z=0.0

Via Lactea 2 (2008)
http://www.ucolick.org/~diemand/vl

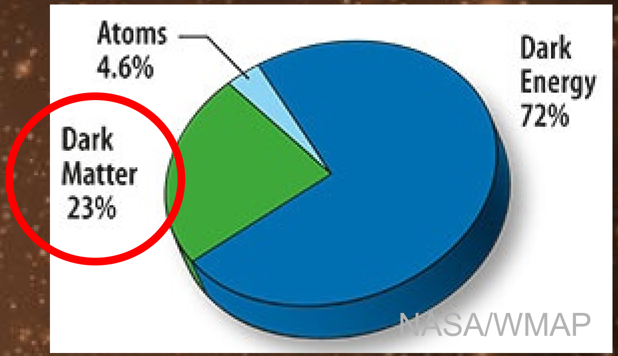
Direct Searches for WIMP Dark Matter

Uwe Oberlack

Rice University

Houston, TX, USA
http://xenon.physics.rice.edu

(moving soon to
Johannes Gutenberg University
Mainz, Germany)



Brookhaven Forum 2010

May 25, 2010

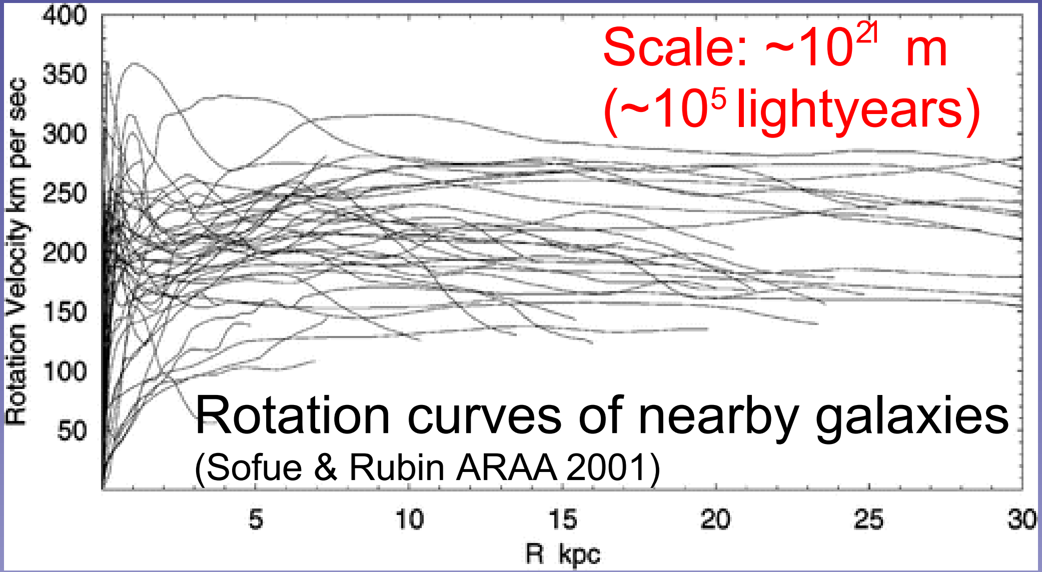
80 kpc

Evidence for Dark Matter in Galaxies and Galaxy Clusters

Spiral Galaxies

Rotation curves remain flat far beyond the edge of the visible disk.

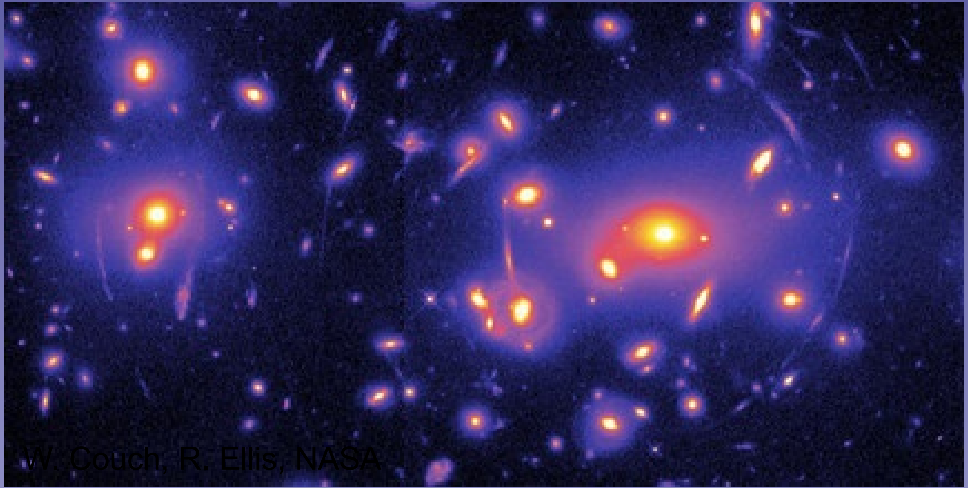
$$\left.\begin{array}{lcl} v(R) & = & \sqrt{GM(R)/R} \\ v(R) & \approx & const \end{array}\right\} \Rightarrow \left\{\begin{array}{lcl} M(R) & \propto & R \\ \rho(R) & \propto & R^{-2} \end{array}\right.$$



Galaxy Clusters

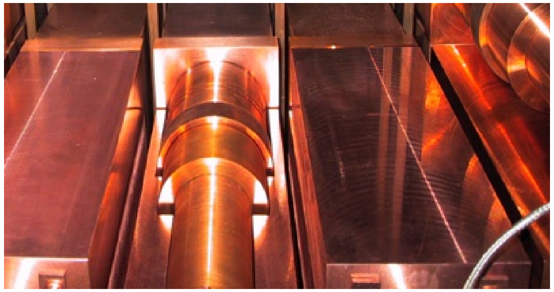
Scale: ~10^{22} m
(~10^6 lightyr)

- Orbital velocities of galaxies > escape velocity (Zwicky's discovery of DM 1933)
- X-ray gas: pressure too great for visible mass.
- Gravitational lensing: measures total mass distribution in clusters.

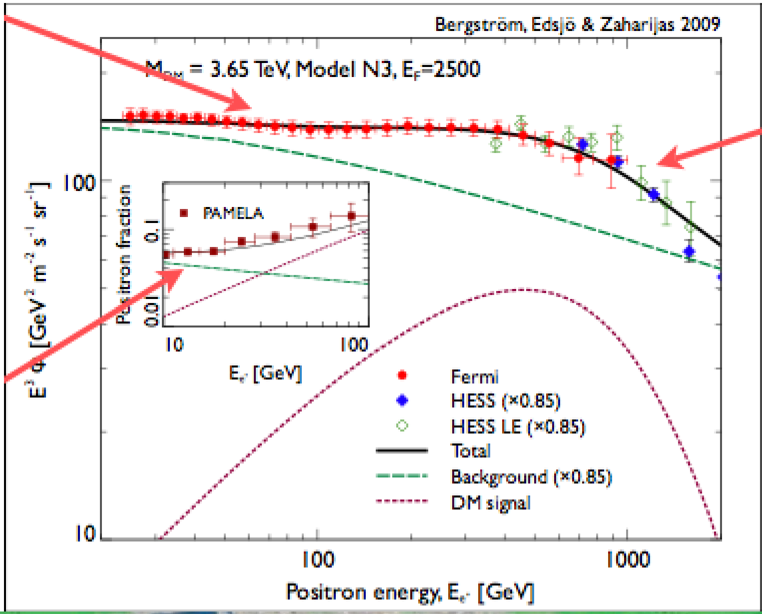


Dark Matter Detection Methods

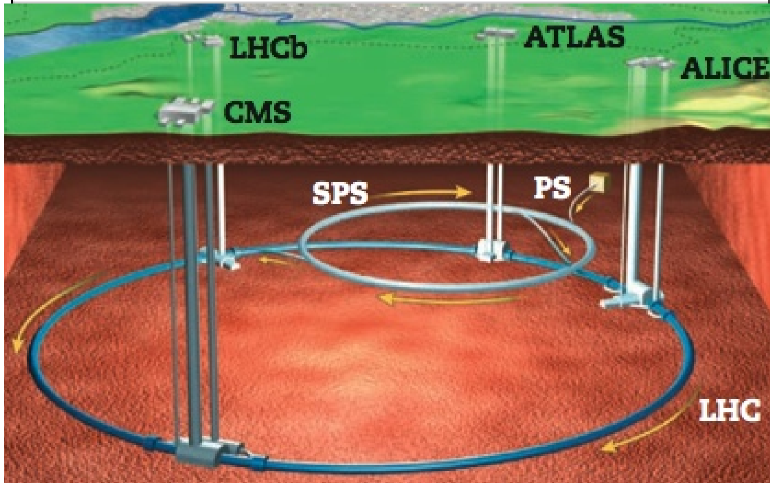
- Astrophysics / Cosmology:
  Measurement of Gravitational Effects.
  - Rotation curves of spiral galaxies
  - Orbital velocities of galaxies in clusters (Zwicky 1933)
  - Colliding clusters (Bullet cluster)
  - Large scale structure, lensing



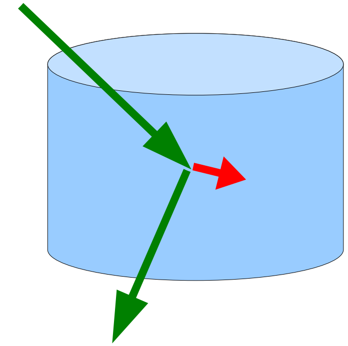
- **Direct Detection:**
  - WIMP scattering
  - Axion searches
- Indirect Detection: from annihilation or decay
  - Cosmic rays
    PAMELA positron excess?
    Fermi, ATIC, HESS electron spectrum? Anti-deuterons?
  - Neutrinos
  - Gamma-rays



- Accelerator-based Creation and Measurement:
  - Missing energy / momentum
  - Search for related particles (SUSY, extra dimensions) even if not the DM particle itself



WIMP Dark Matter Direct Detection



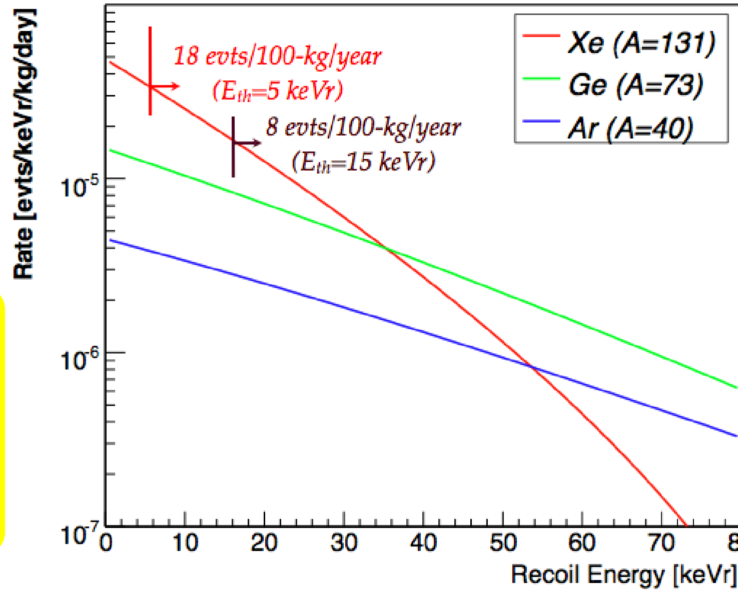
- Dark Matter is non-bayonic, (rather) cold, ...

  if a thermal relic from the Big Bang ...

  Weakly Interacting Massive Particles: WIMPs
- Scattering of WIMPs χ off of nuclei A.
  - elastic or inelastic?
  - spin-independent (~A^2) or spin-dependent?
- Energy spectrum:

$$\frac{dR}{dE} = \frac{\rho_\chi \sigma_s}{2 m_\chi \mu^2} |\boldsymbol{F}(E)^2| \int_{v_{min}}^{v_{esc}} \frac{f(\boldsymbol{v}, t)}{v} d^3 v$$

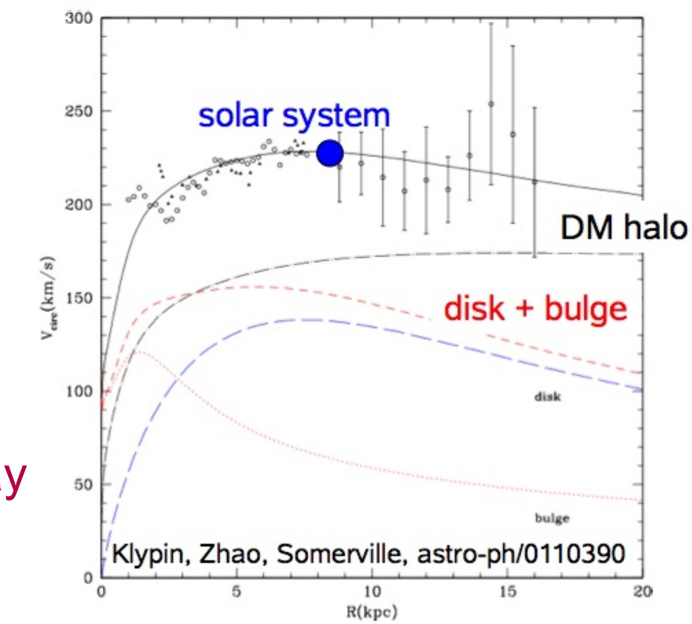
$$f(\boldsymbol{v}, t) \propto \exp\left(\frac{-(\boldsymbol{v} + \boldsymbol{v}_E(t))^2}{2 \sigma_v^2}\right)$$



  - $m_\chi \sim 10 - 10^4$ GeV/c², $\mu = (m_\chi m_n)/(m_\chi + m_n)$
  - $v_\chi \sim 230$ km/s
  - "Standard" spherical halo:

    Featureless recoil spectrum <E> ~ O(10 keV)
  - ρ_χ/m_χ: local number density of WIMPs
  - $\rho_\chi \sim 0.3$ GeV/c²/cm³, $\rho_\chi/m_\chi \lesssim 10$ / L
  - σ_s cross section per nucleus.

Rate < 10^{-2} events / kg / day



Backgrounds in Direct DM Search

Cross-sections are *very* small: $<10^{-43}$ cm^2 or 10^{-7} pb (spin-independent)

Without background, sensitivity $\propto$ (mass × exposure time)$^{-1}$

With background subtraction $\propto$ (M t)$^{-1/2}$ until limited by systematics.

Backgrounds:

Gamma-rays & beta decays:

- ~100 events/kg/day
- Need very good β and γ background discrimination.
- Shielding: low-activity lead, water, noble liquids (active), liquid N_2, ...

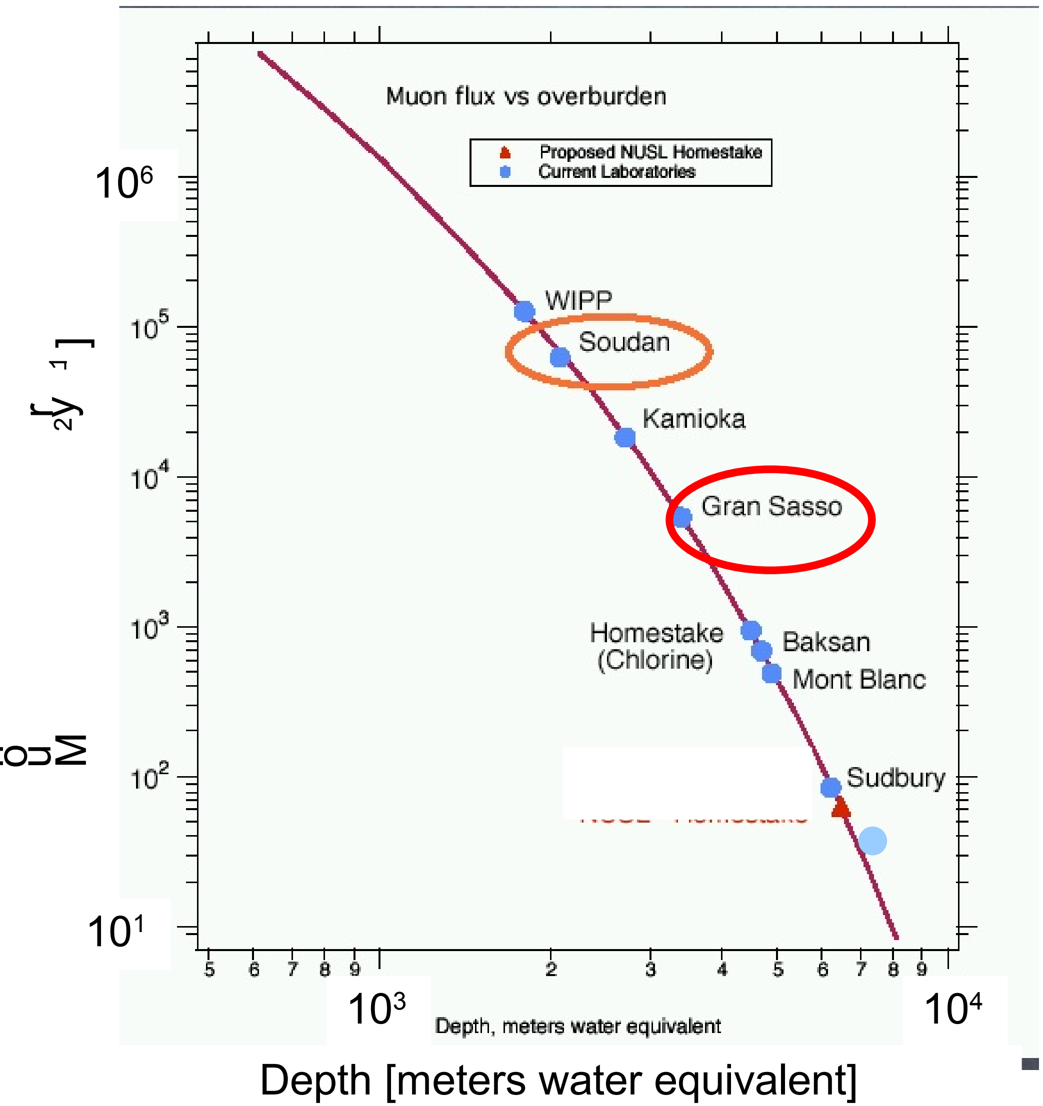
Neutrons from (α, n) and spontaneous fission (concrete, rock, etc.):

- ~ 1 event/kg/day (LNGS)
- Neutron moderator (polyethylene, paraffin, ...)

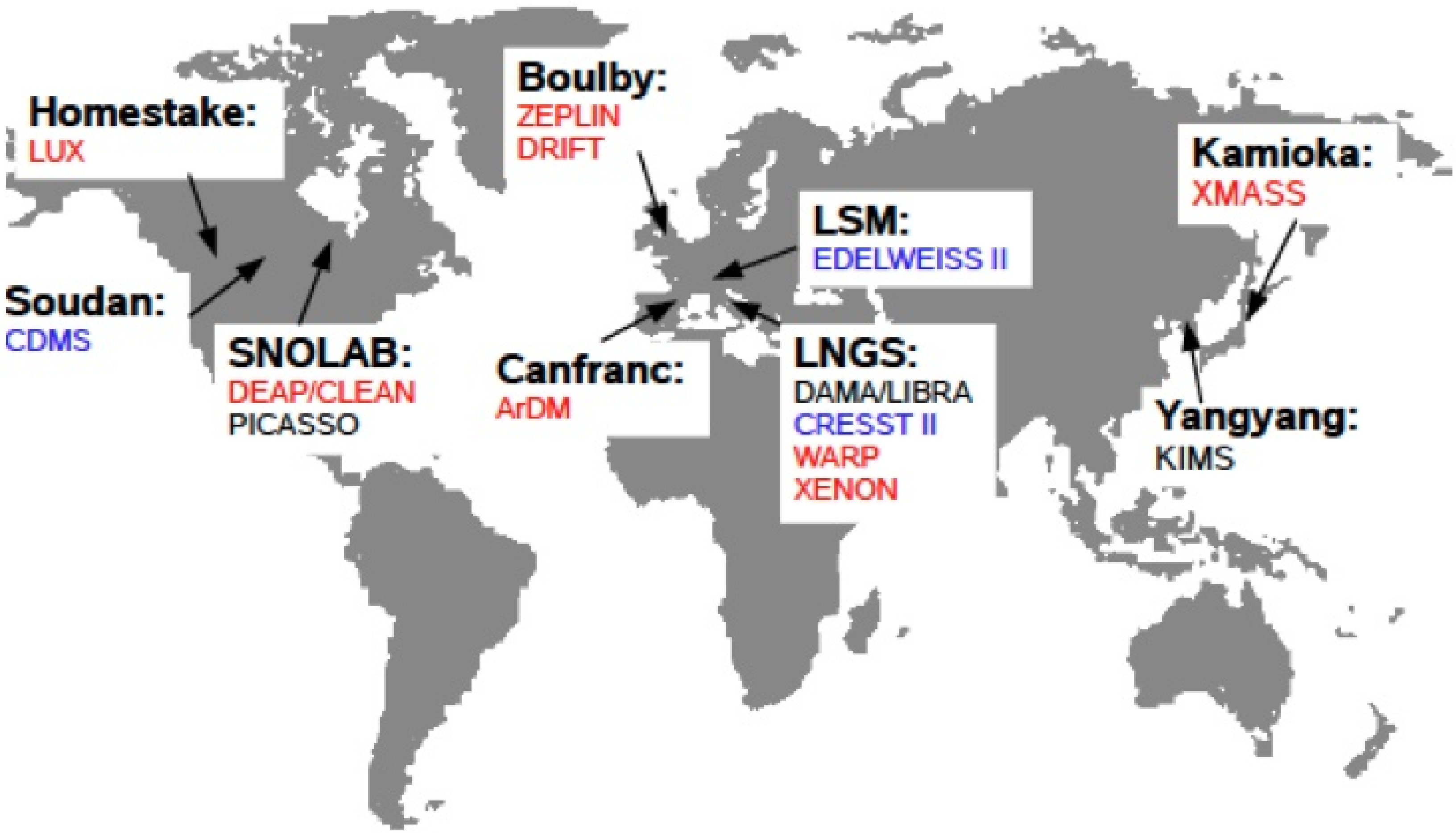
Neutrons from CR muons:

- Rate depending on depth.
- μ-veto, n-veto, shielding

α decays from Rn daughters, ...



Worldwide Searches for WIMP Dark Matter



- Cryogenic (phonon) detectors
- Noble Liquid detectors
- Other technologies

DM Detector Overview
Detection Principles

Bubble Formation
COUPP, PICASSO

Tracking
Drift, DM-TPC, NIT

Ionization
CoGeNT, GERDA,
MAJORANA

CDMS-II
EDELWEISS-II

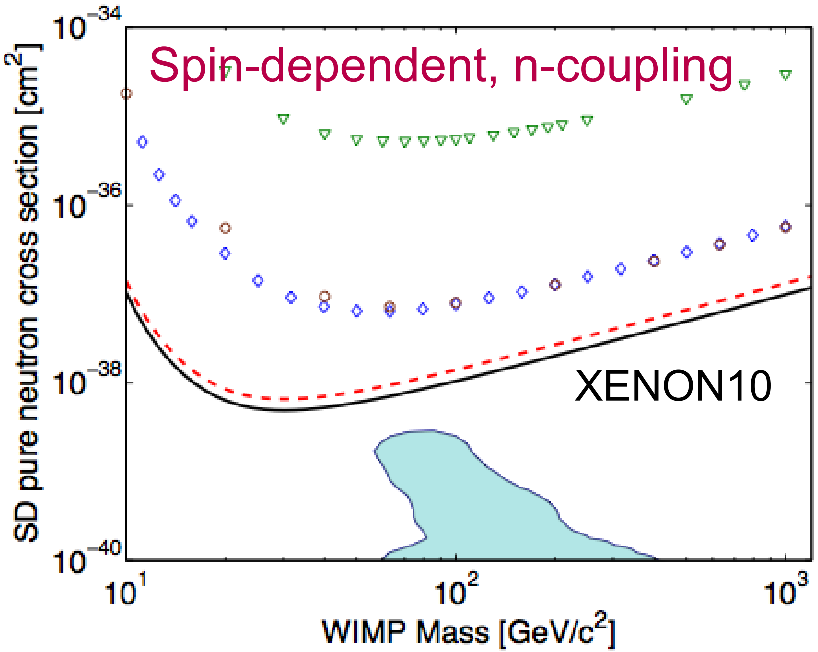
LAr: WARP, ArDM
LXe: **XENON**, LUX, Zeplin

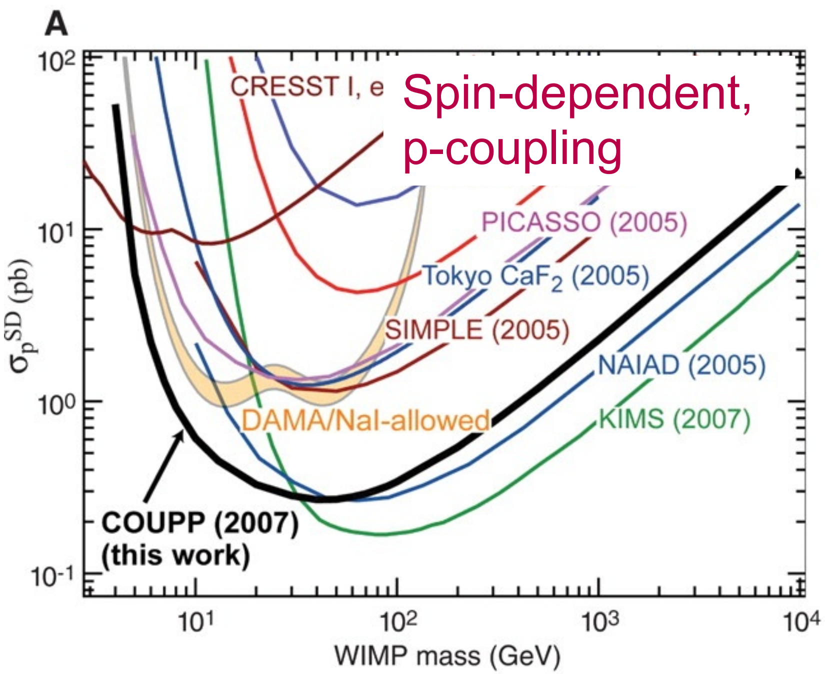
Phonons
CRESST-II

CRESST-II,
ROSEBUD

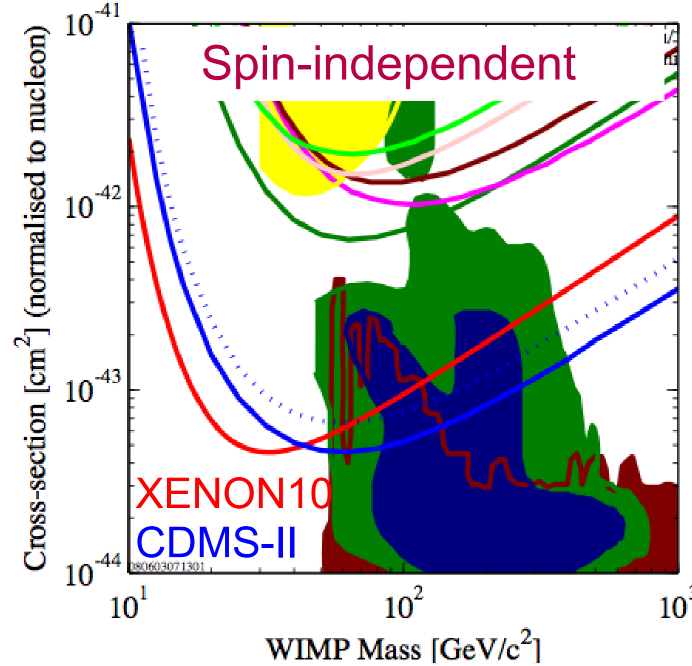
Scintillation
DAMA/LIBRA
KIMS, XMASS,
DEAP/CLEAN

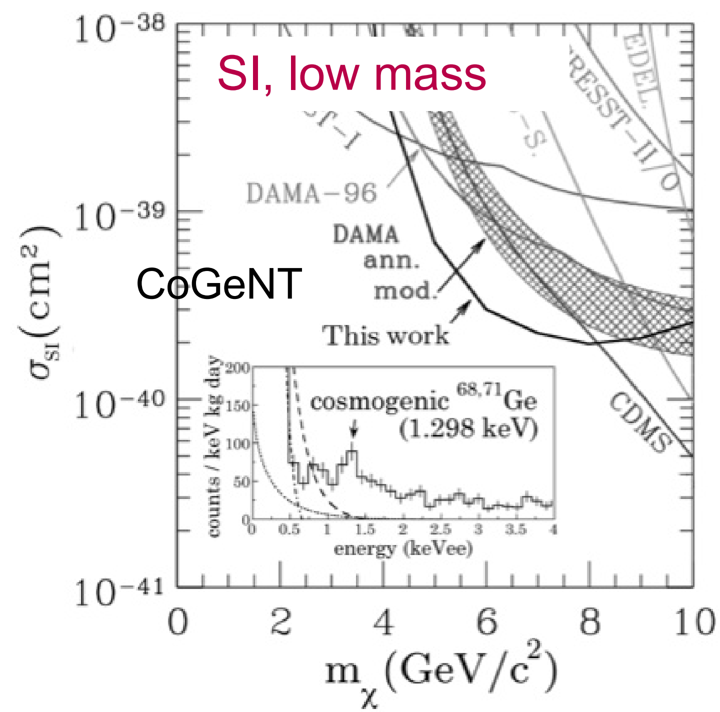
Current Status in WIMP DM Sensitivities (2009)



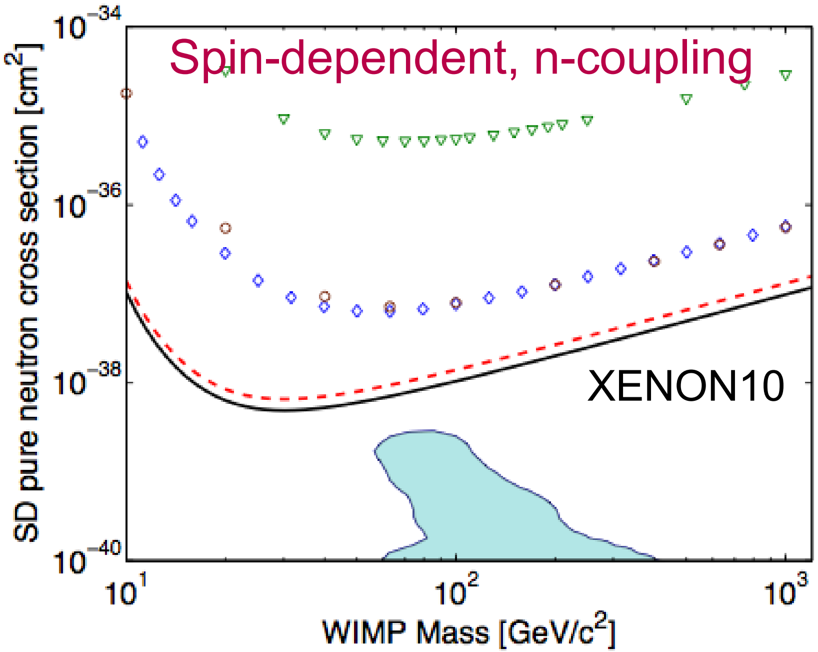


- J. Angle et al., 2008 PRL 101 091301 (XENON10 SD)
- J. Angle et al., 2008 PRL 100 (2) 021303 (XENON10 SI)
- Z. Ahmed et al., arxiv:0802.353v1 (CDMS-II SI)
- C.E. Aalseth et al. arxiv:0807.0879v1 (CoGeNT SI)
- E. Behnke et al., 2008 Science 319, 933 (COUPP SD)
- Recent additions (not plotted): Zeplin-III SI, SD arxiv:08/09 limits ~ Xe10





Current Status in WIMP DM Sensitivities (2010)



XENON10 SD, 2008
PRL 101 091301

XENON10 SI, 2008
PRL 100 (2) 021303

XENON100 SI, 2010:
arxiv:1005.0380,1005.2615

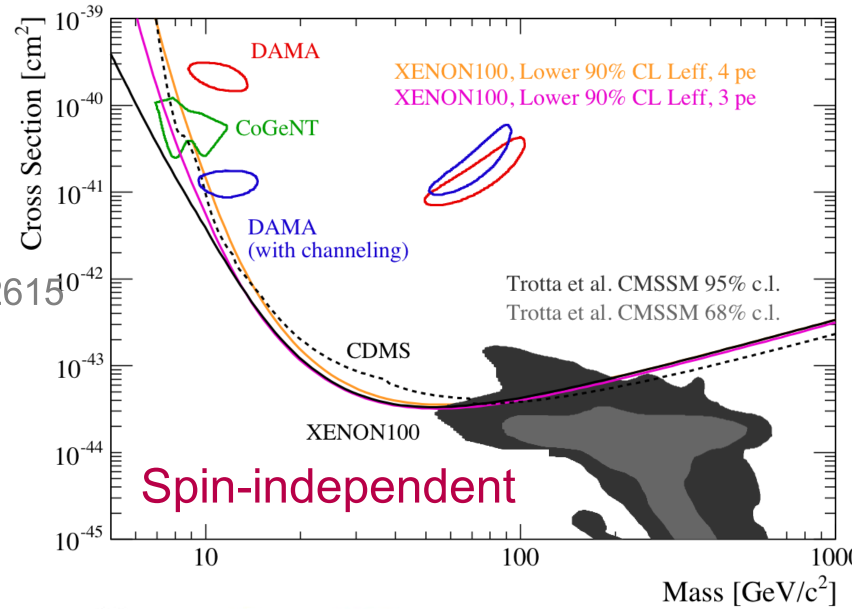
CDMS-II, 2010:
Science 327, 1619

CoGeNT SI:
arxiv:1002.4703

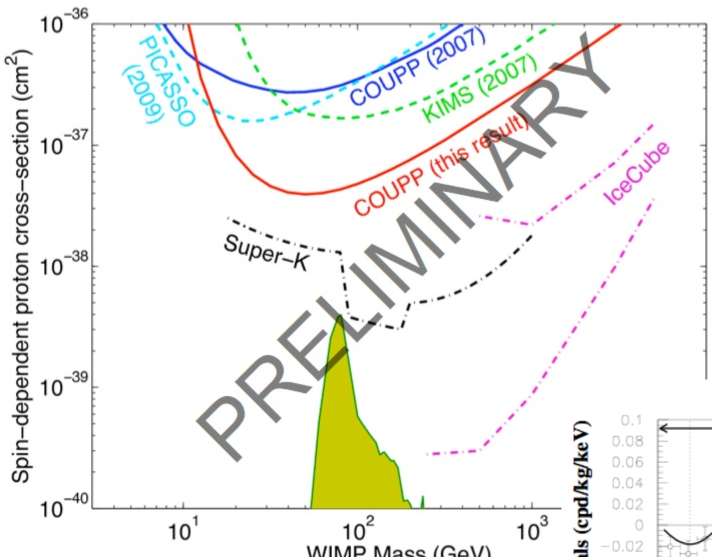
DAMA/LIBRA, 2010:
arxiv:1002.1028

COUPP SD:
2008: Science 319, 933
2010 prelim: DM2010 conf.

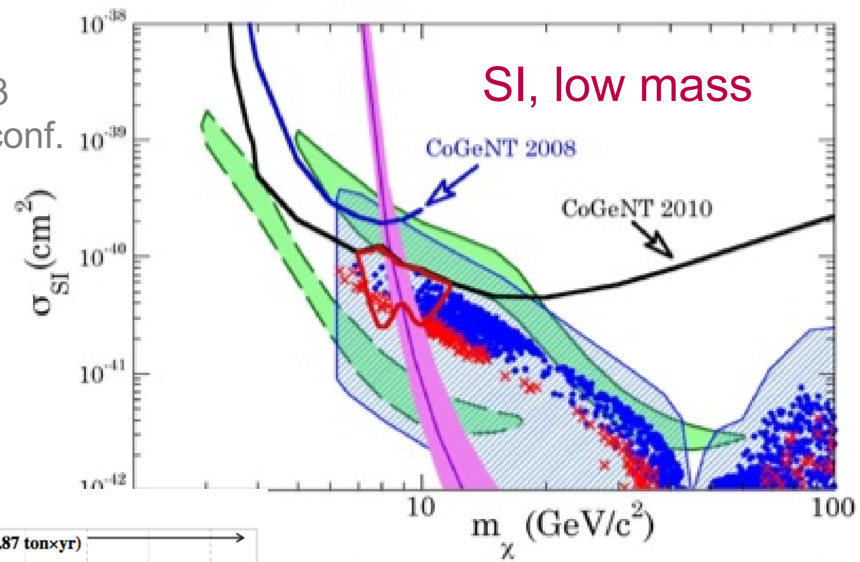
PICASSO SD, 2009:
Phys.Lett. B 682, 185



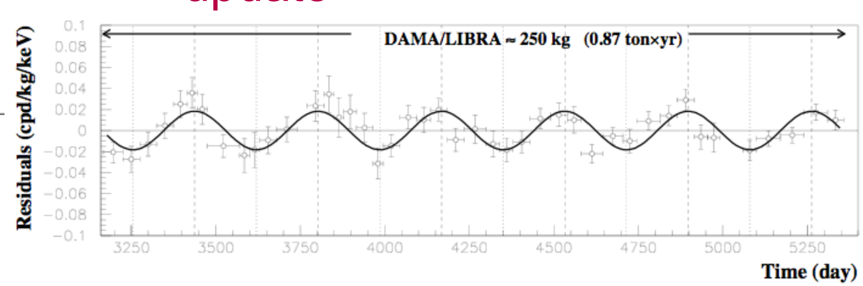
Spin-dependent, p-coupling



C.E. Dahl, DM2010
February 26, 2010

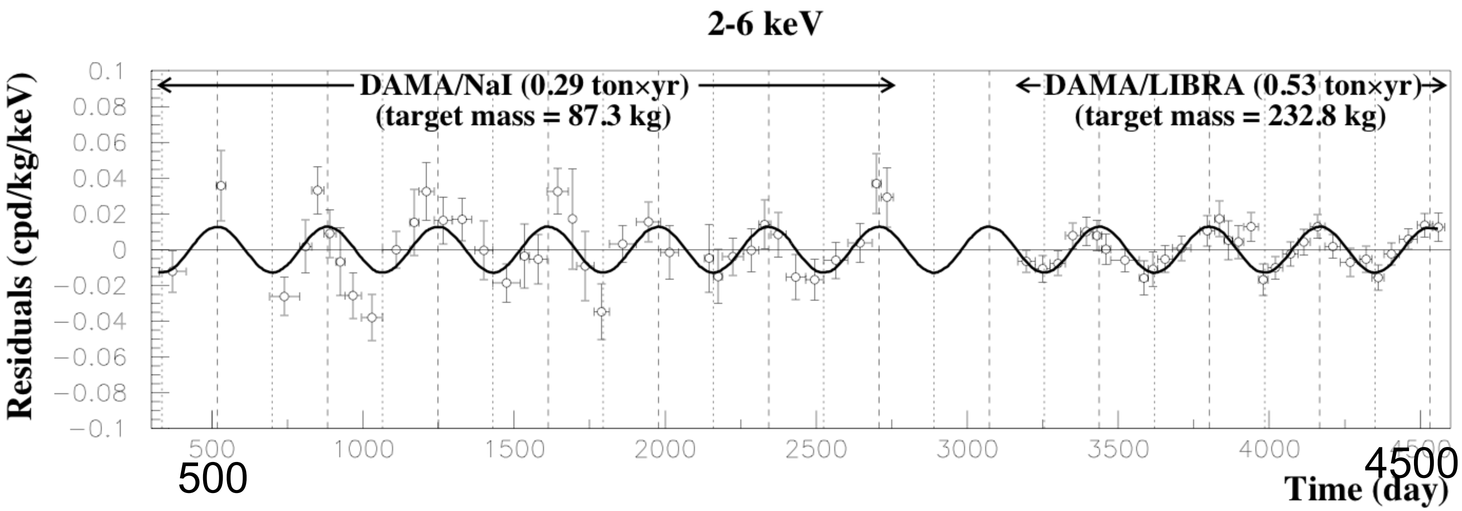


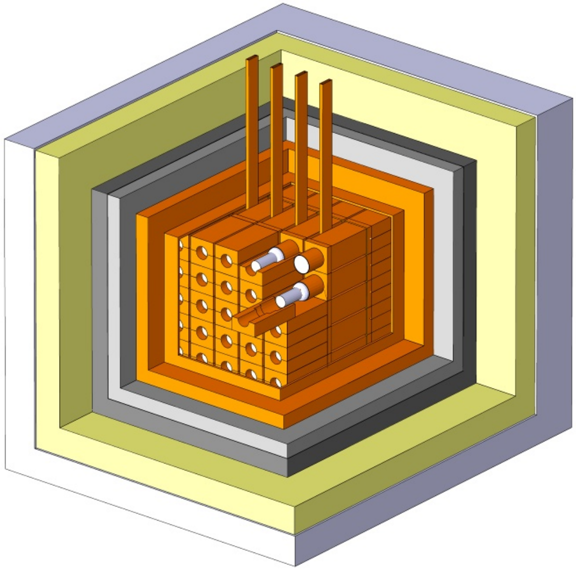
Annual modulation update



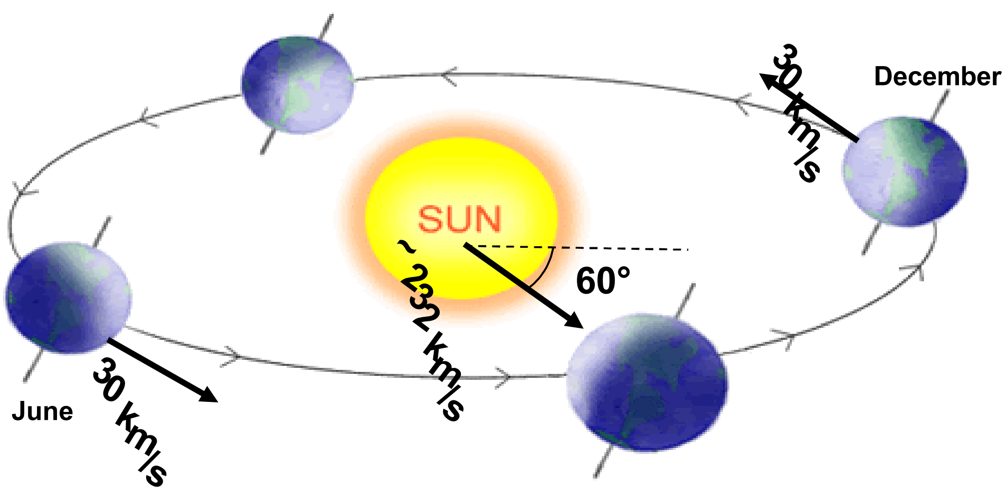
DAMA/LIBRA Annual Modulation

R. Bernabei et al. arxiv:0804.2741, arxiv:1002.1028





~250 kg of NaI counters
1.17 ton-year exposure
(2010)

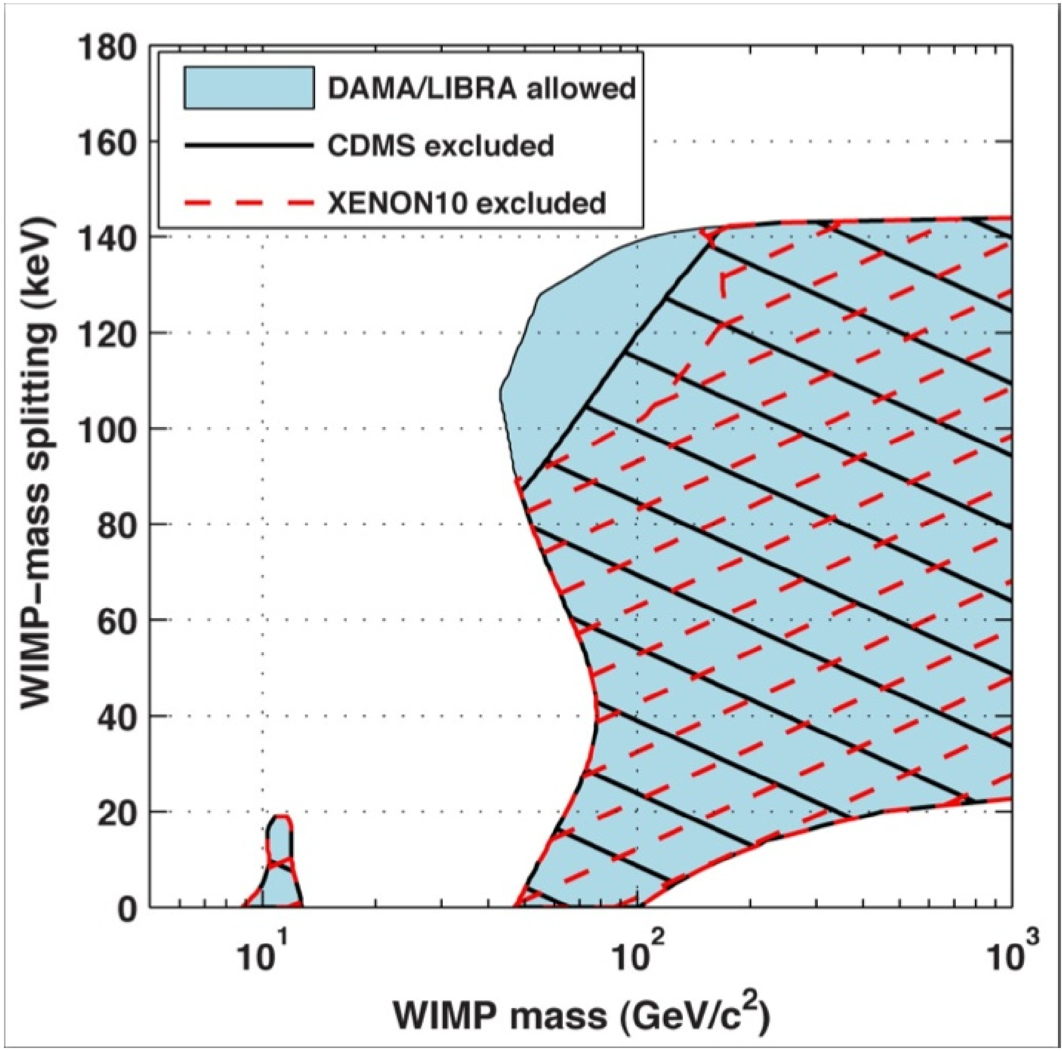


- Modulation in 2-6 keV single hits: 8.9 σ
- Mostly in 2-4 keV, ~0.02 cts/d/kg/keV
- Total single rate ~1 cts/d/kg/keV
- Standard DM distribution: ~5% modulation
- Period & phase about right for DM.
- No annual modulation in 6-14 keV.
- No annual modulation in multiple hits. (statistics?)
- **DM detection?**
- Conflict with other experiments in standard scenarios that test the larger steady state effect! **Inelastic DM? Low mass WIMPs?**

Drukier, Freese, Spergel PRD 86
Freese et al. PRD 88

Inelastic Dark Matter Limits

- Assume DM can scatter only in a low-lying excited state, i.e., elastic scattering is suppressed.
- This makes DAMA/LIBRA annual modulation still compatible with XENON10 & CDMS in a parameter space with energy splitting ~90 – 140 keV at WIMP masses 50 – 140 GeV/c^2.
- XENON100 will cover the entire allowed parameter space at very low background – but will require good low energy calibration.



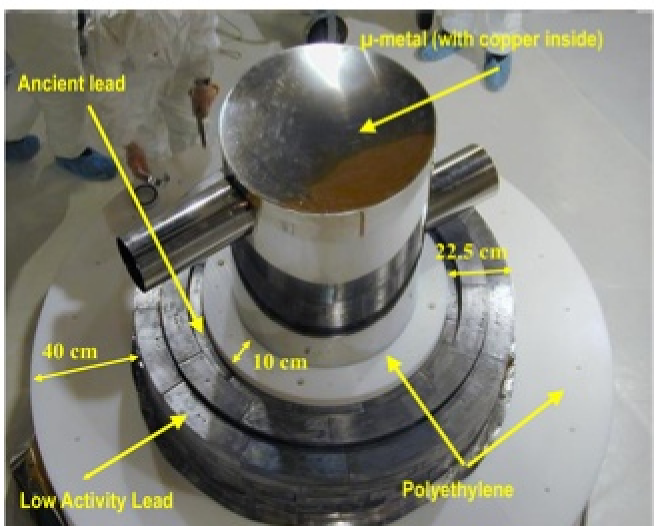
Cryogenic Germanium: CDMS-II, Edelweiss-II

Collaboration: 16 US institutions + Queens/Canada + U Zurich/Switzerland

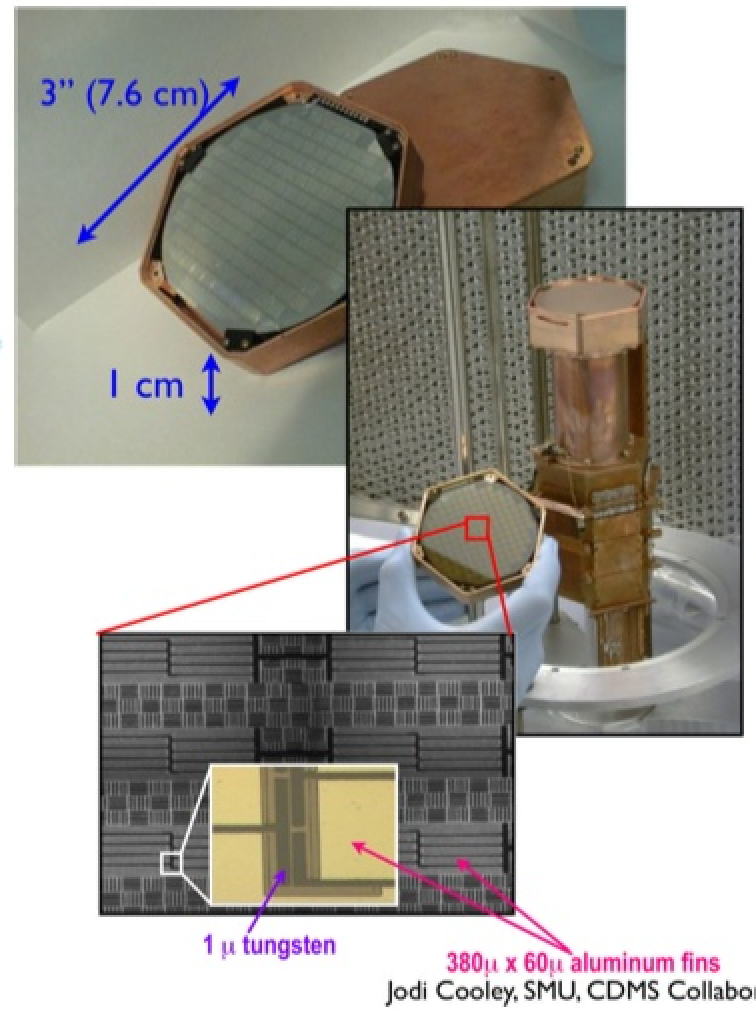
located in Soudan underground mine:

Detectors: 30 cryobolometer
- 19 Ge (230g), 11 Si (100g)
- in 5 stacks inside background shield

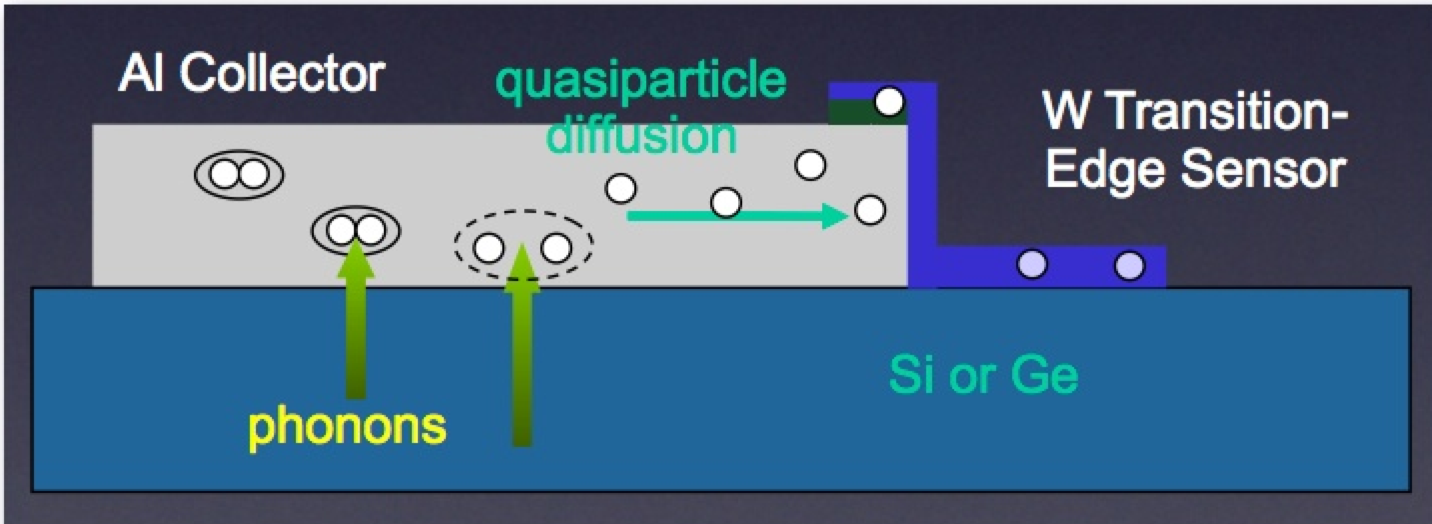
- with heat (phonons thermalized and athermals)
- and ionisation readout



not shown: active μ-veto



CDMS-II Operating Principle: Measurement of Charge and Phonons



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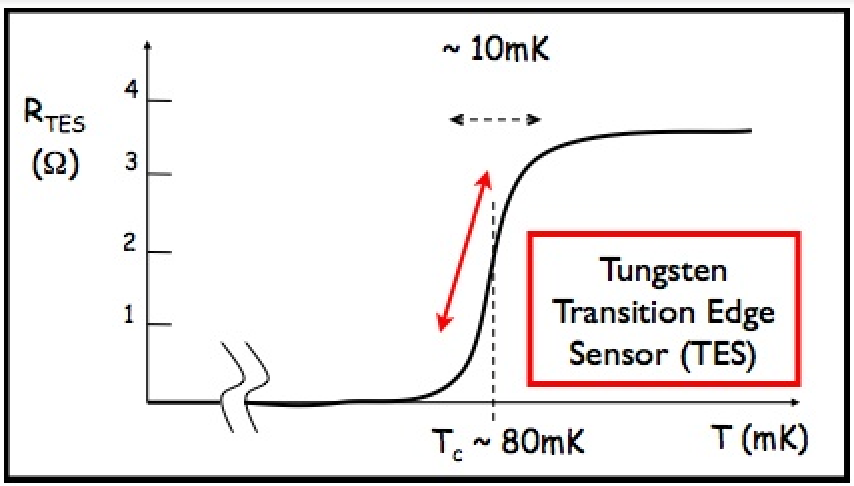
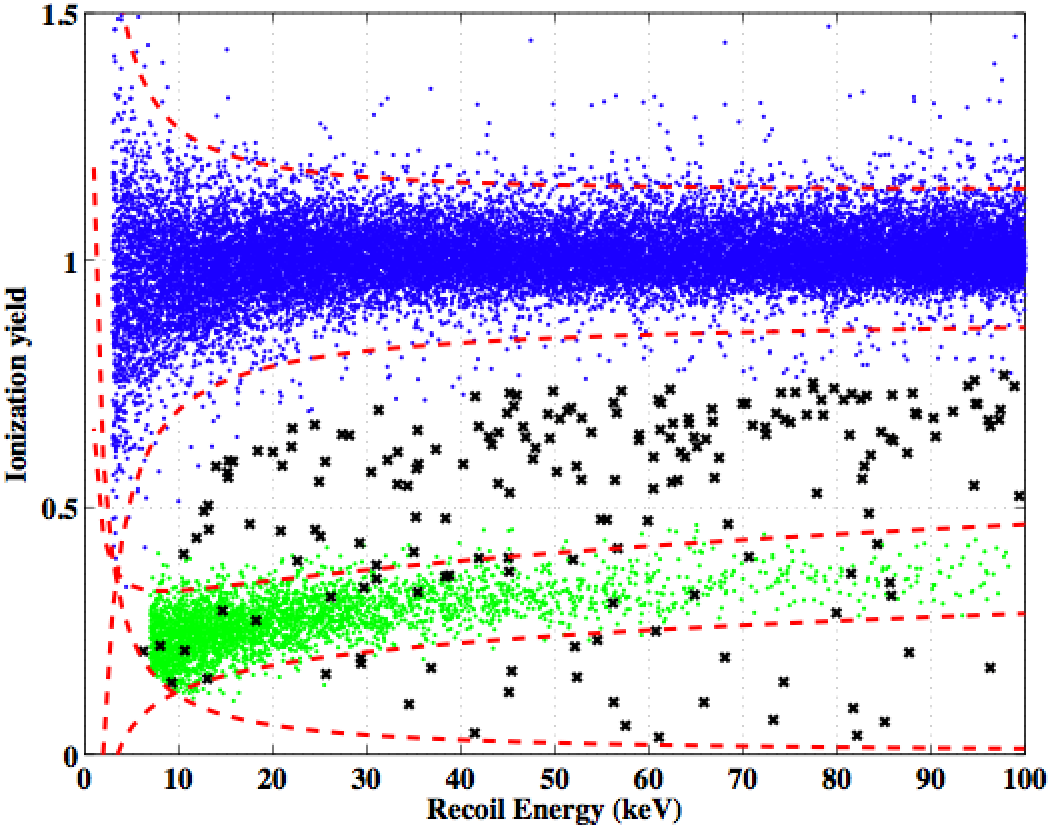


4 SQUID readout channels, each reads out 1036 TESs in parallel

CDMS-II Surface Background

- Most backgrounds (e, γ) produce electron recoils
- WIMPS and neutrons produce nuclear recoils.
- Ionization yield (ionization energy per unit phonon energy) strongly depends on particle type.
- Particles that interact in the "surface dead layer" result in reduced ionization yield.



SLAC, Dec. 17, 2009

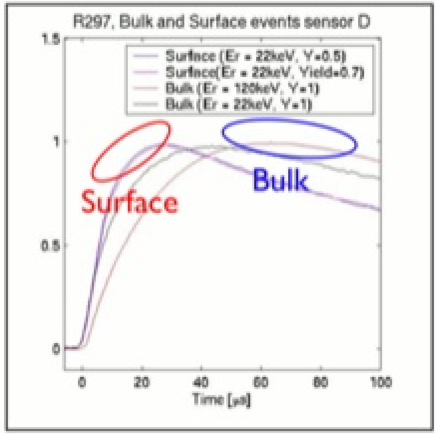
22

Jodi Cooley, SMU, CDMS Collaboration

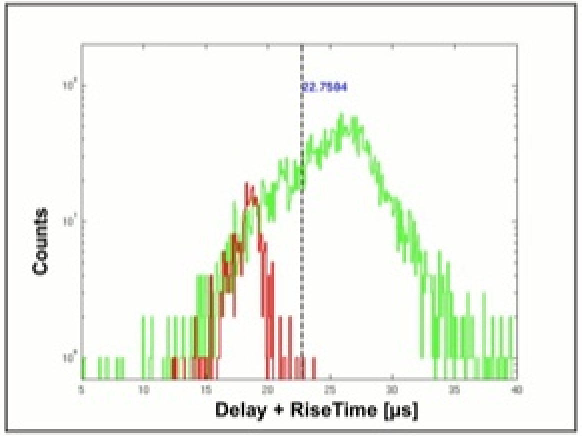
CDMS-II Background Suppression

Solution for surface contamination events:

⇒ detection of athermal photons to become sensitive to surface events at separation efficiency 10^{-6}

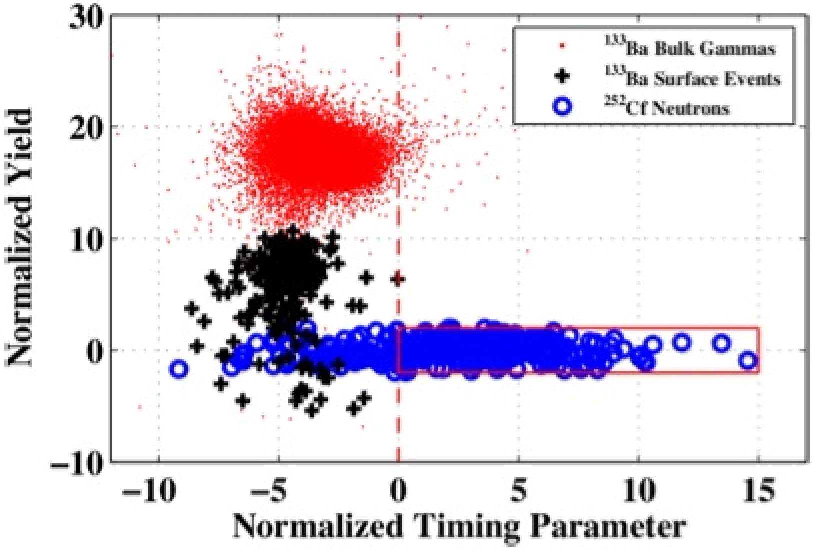


Phonons near surface travel faster, resulting in shorter risetimes of phonon pulse.



Selection criteria set to accept ~0.5 background events.

J. Cooley, SLAC, Dec 17, 2009

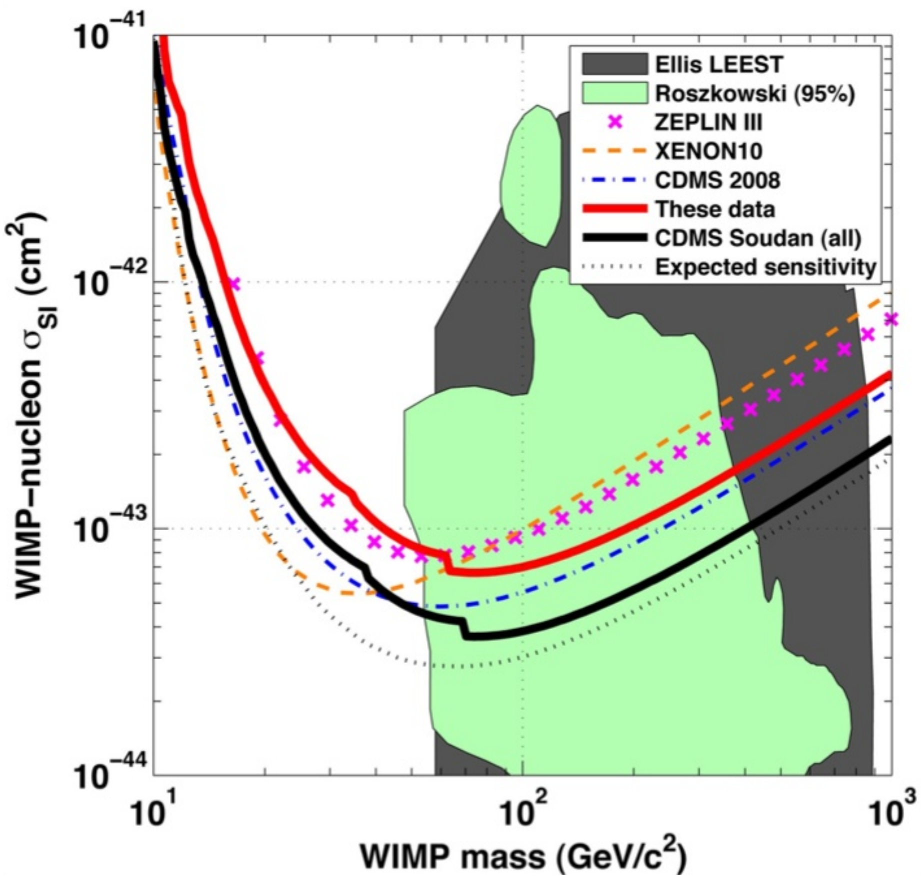


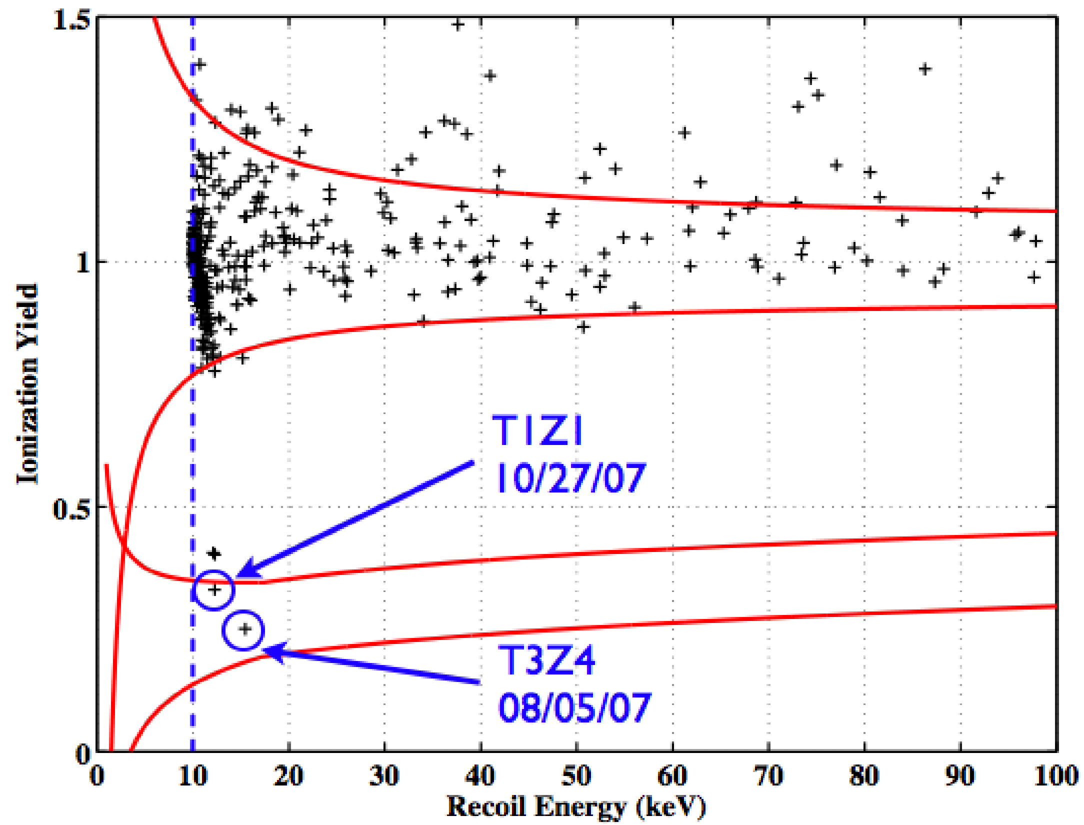
arXiv:0912.3592

CDMS-II Final Result

science.1186112 (2010)

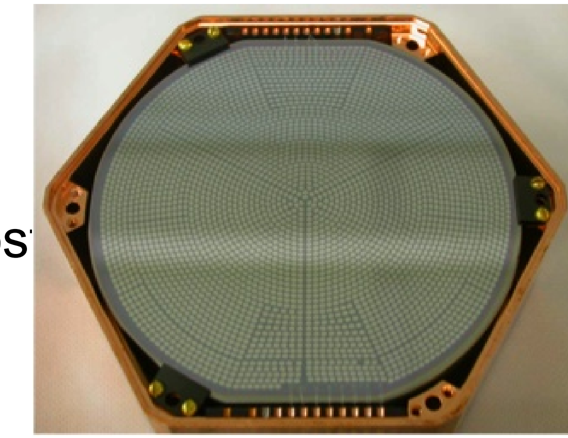
- 2 events observed after all cuts.
- Pre-opening background estimate: 0.6 events
- Revised estimate: 0.8 +/- 0.1 events
- 23% chance for background.

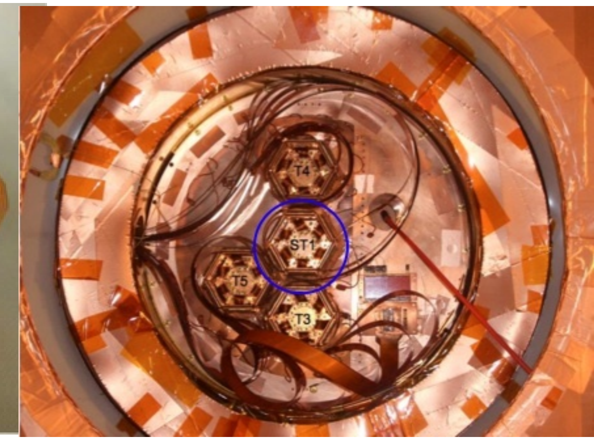


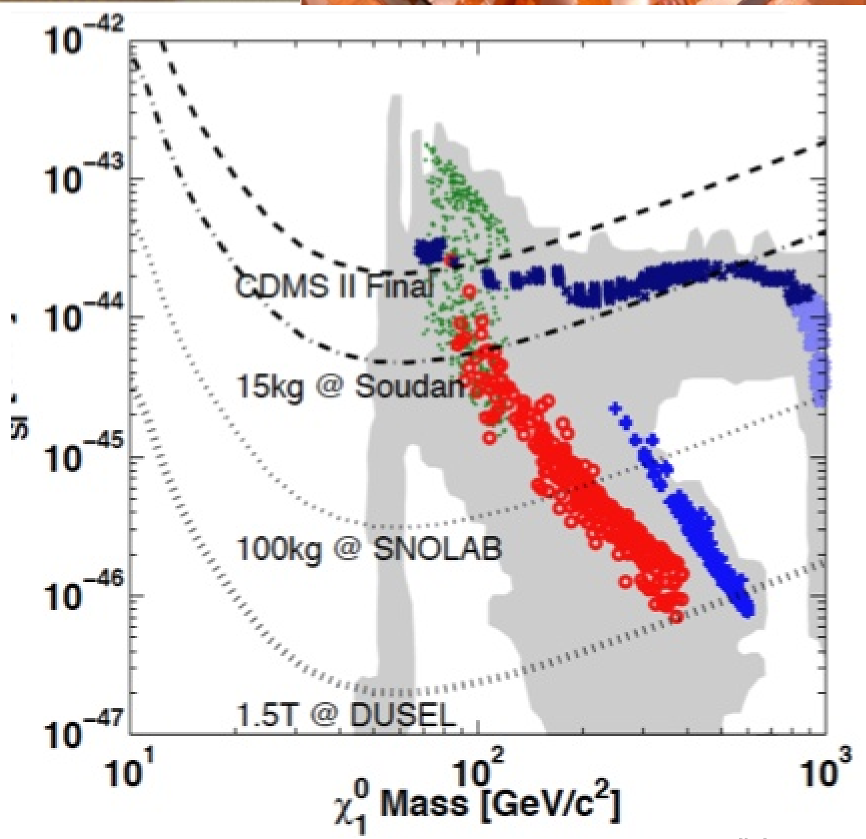


New Technologies for Large-Scale Cryogenic Germanium: Super-CDMS, Edelweiss / EUREKA

- Use semi-conductor industry production style to improve reproducibility and yield, reduce cost
- Increase size of detectors.
  (250 g -> 607 g in Super-CDMS)
  Even 5 kg detectors possible?
- Initially Super-CDMS will remain in Soudan mine (~15 kg). Later: ~100 kg scale at deeper site (SnoLab).
- EDELWEISS: success with surface background suppression using interleaved electrodes. Much superior over timing cut!
  Similar effort ongoing at CDMS (iZip).

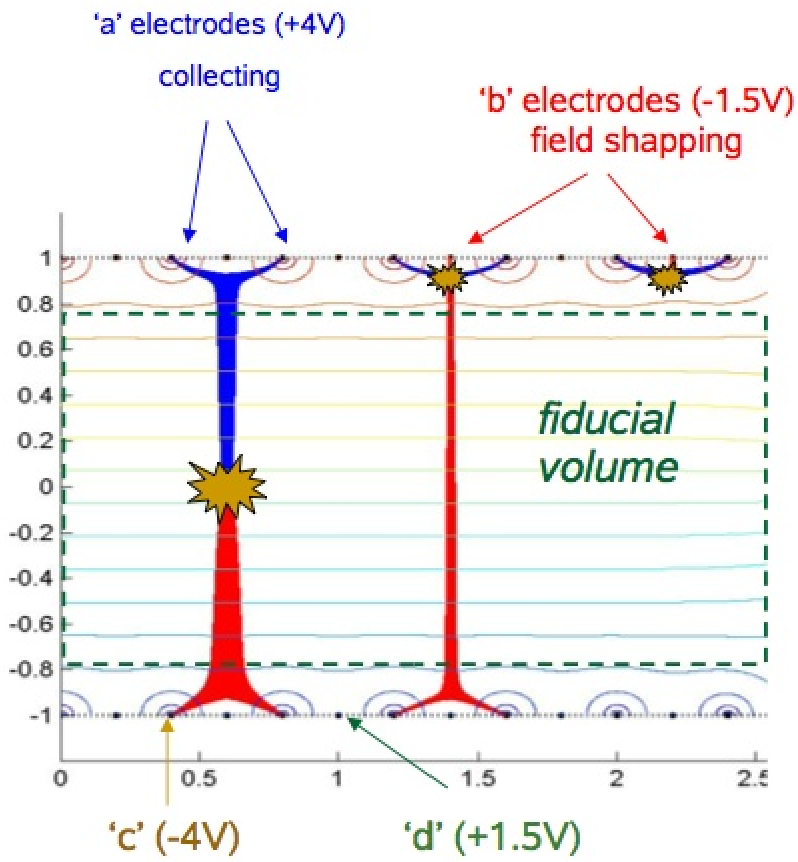


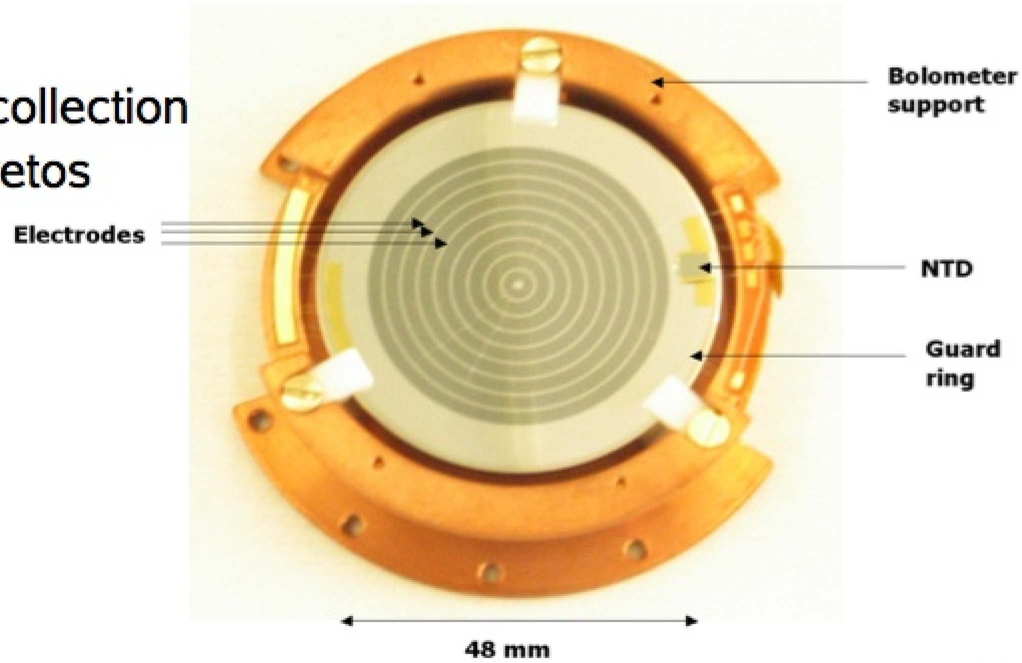




Edelweiss – Interleaved Electrodes

Near surfaces:
Transversal E field to suppress charge collection to other side, use ‘b’ and ‘d’ signals as vetos without changing bulk field



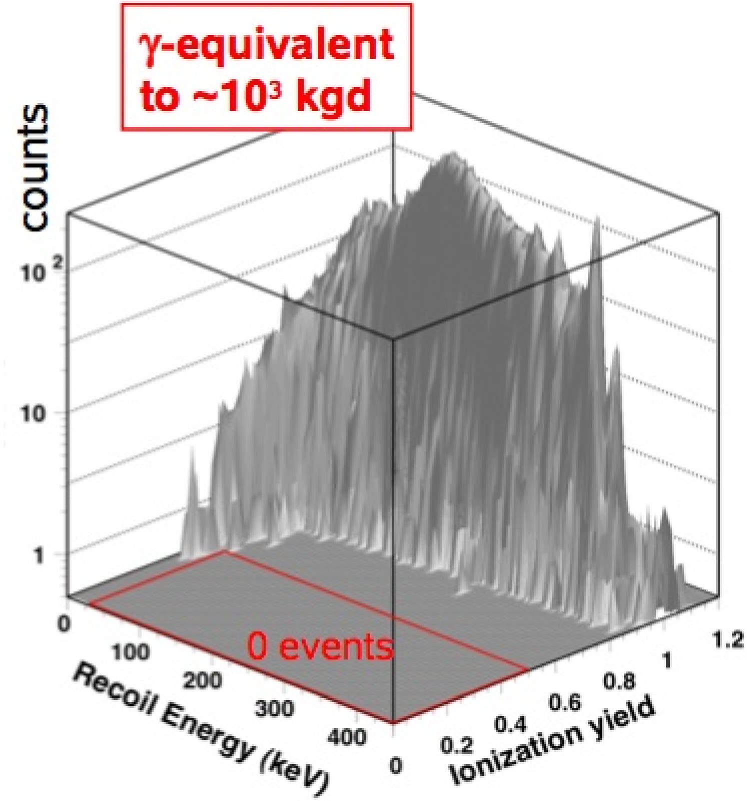


First detector built 2007
1x200g + 3x400g tested in 2008
10x400g running since beginning 2009

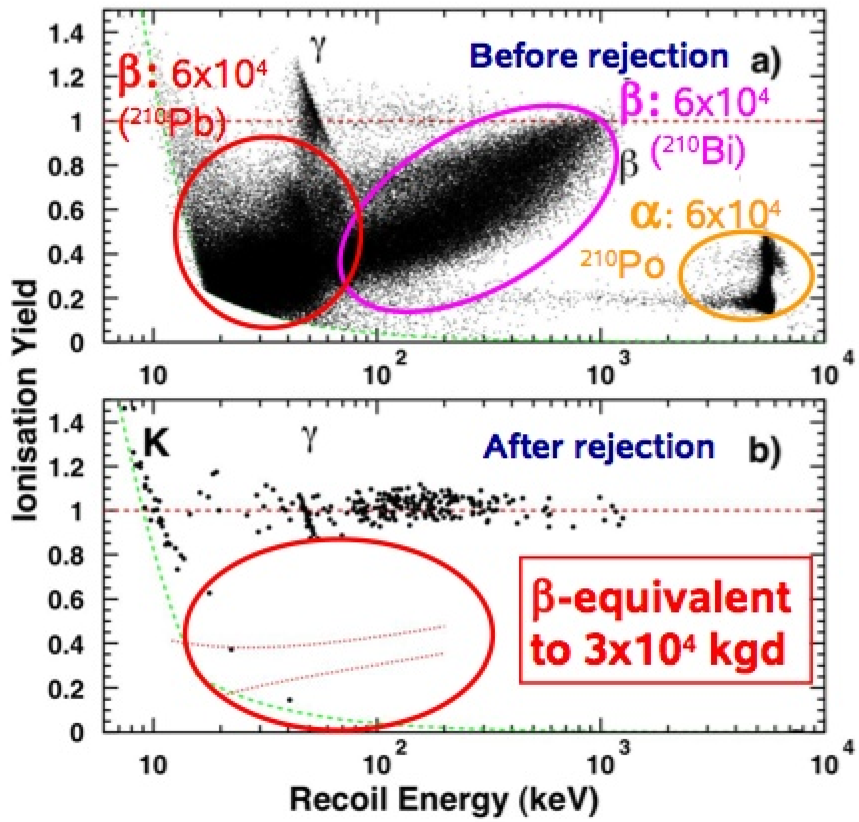
E. Armengaud, Colliquium APC, Feb 2010

Performance of Interleaved Electrode Detectors

- **Gamma rejection**
  ~1 month ^{133}**Ba** calibration (~10^5 γ's)



- **Beta rejection**
  ^{210}**Pb** source

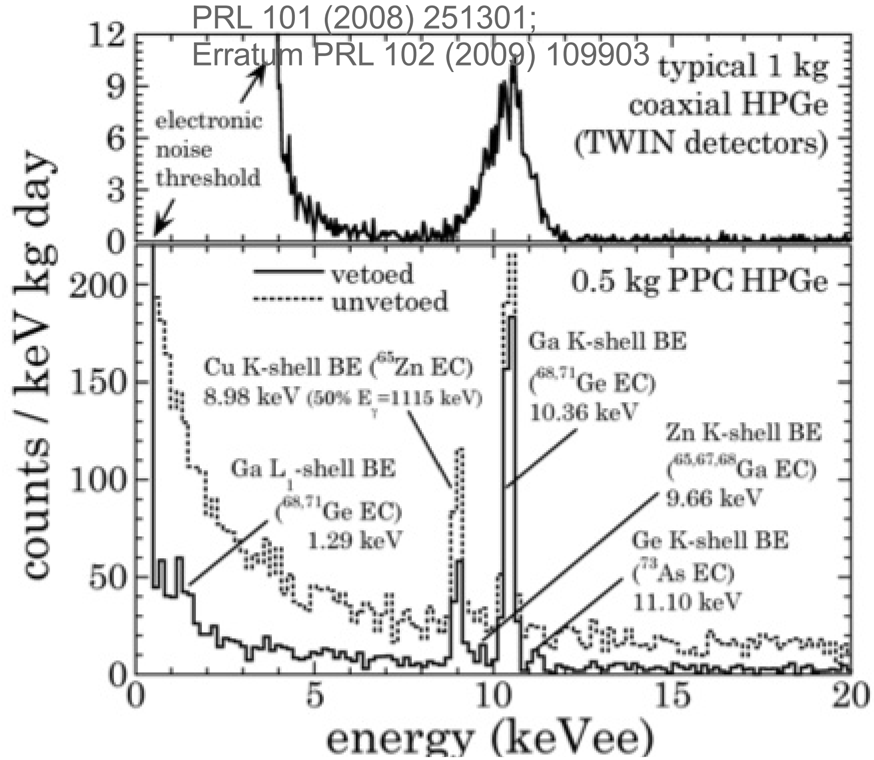


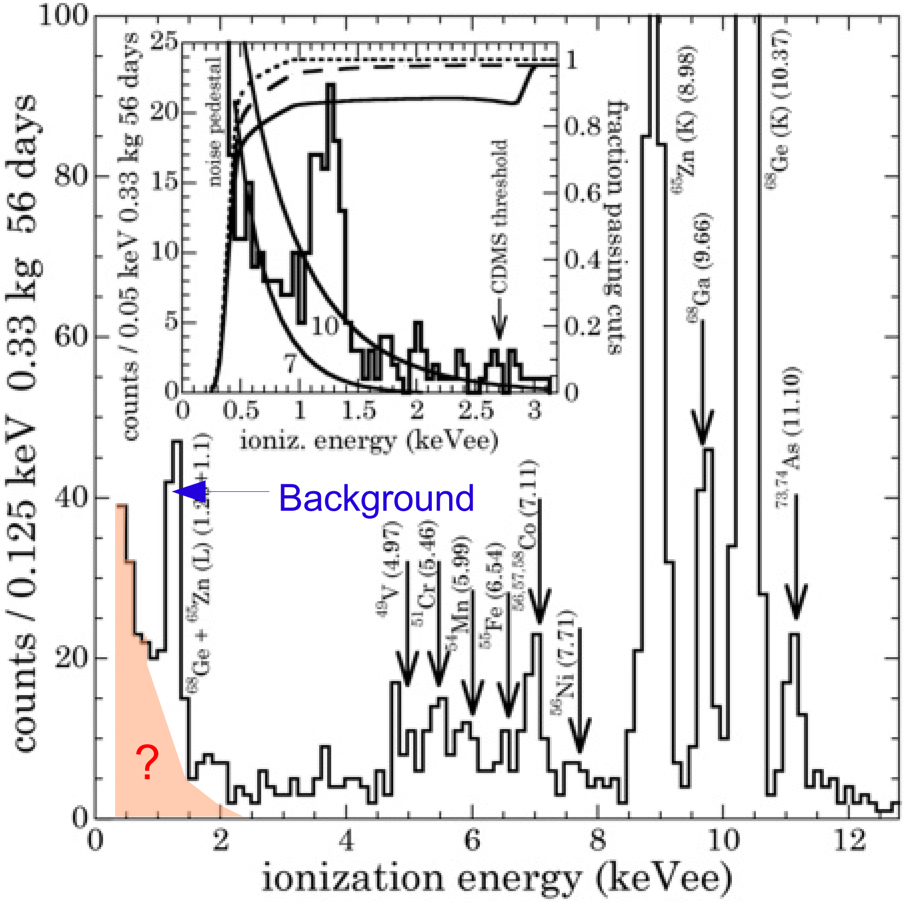
Phys Lett B 681 (2009) 305-309 (arXiv:0905.0753v1)

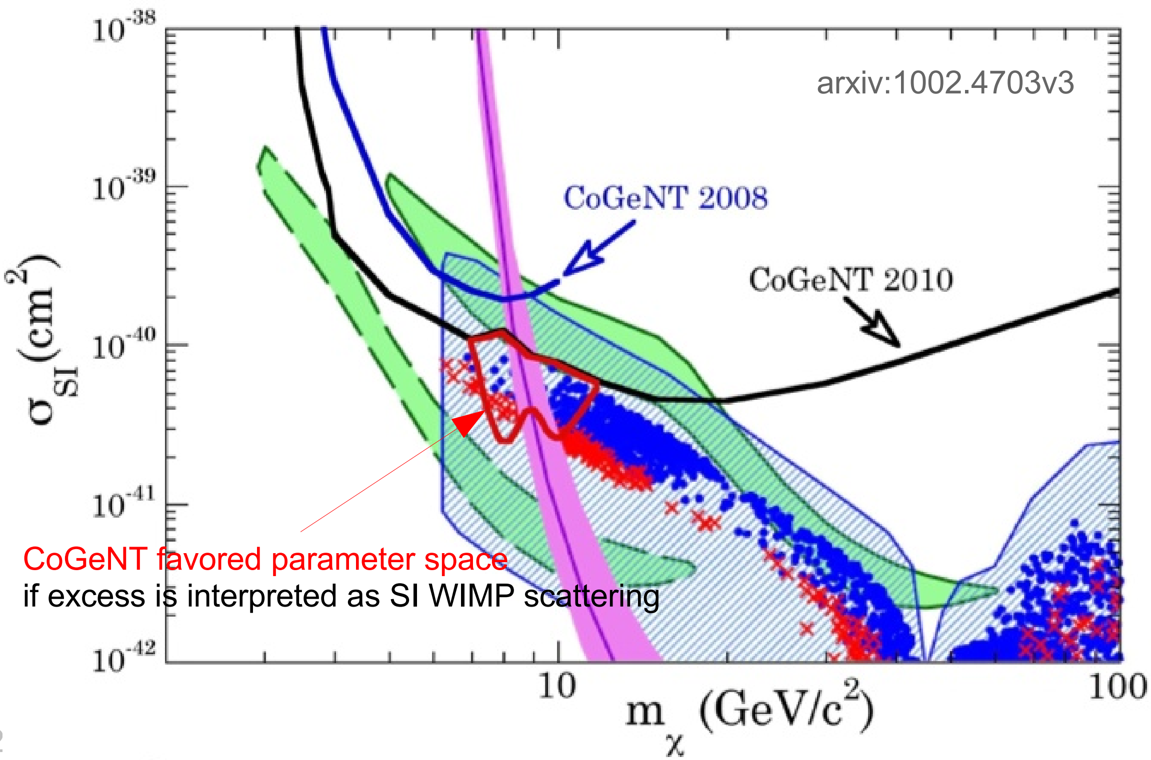
E. Armengaud, Colliquium APC, Feb 2010

CoGeNT: Have we found Low Mass WIMPs?

- P-type point contact (PPC) Germanium detectors:
  - 440 g mass per detector (CDMS: 250 g)
  - low electronic noise, hence low threshold (0.4 keVee)
- Located in Soudan mine (2100 mwe)

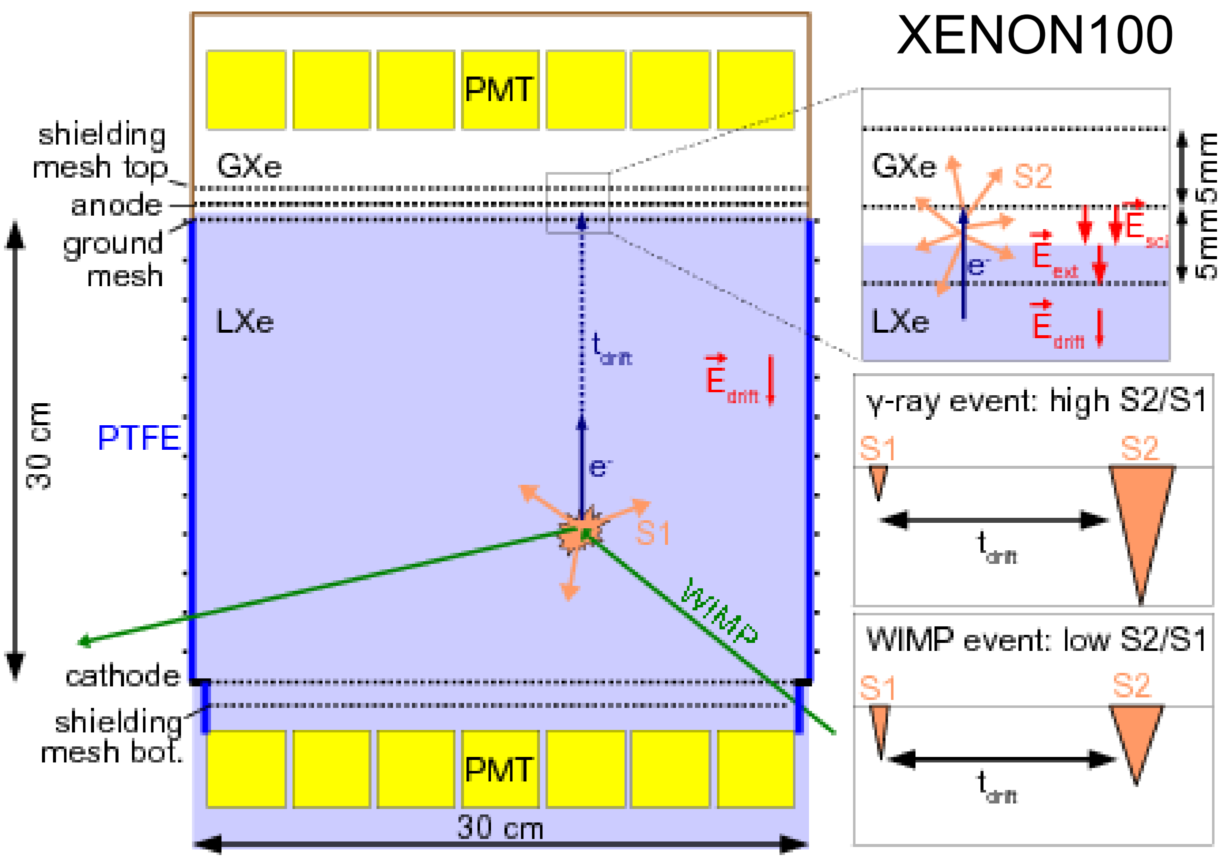






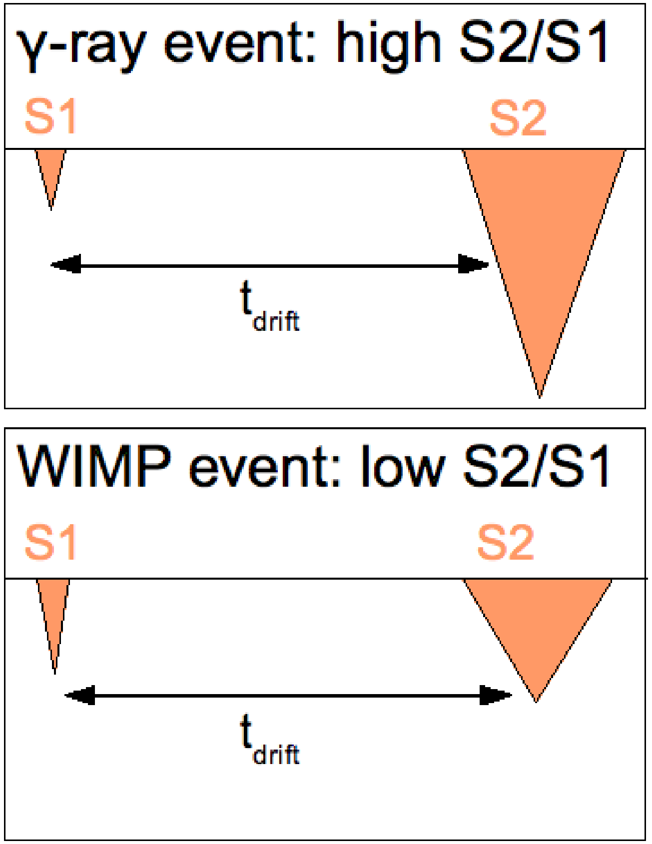
The Liquid Xenon Dual Phase TPC

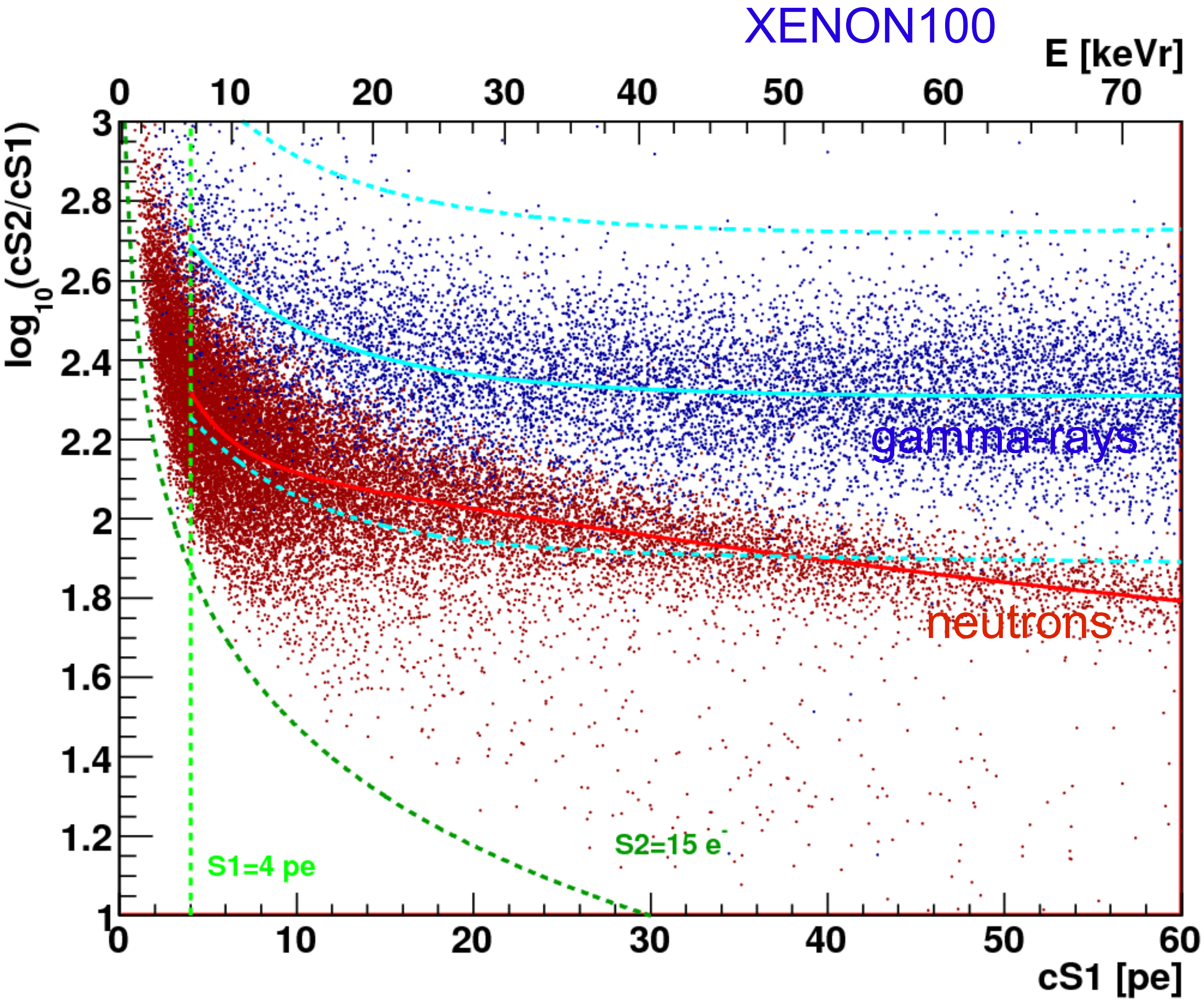
- Wimp recoil on Xe nucleus in dense liquid (2.9 g/cm^3)
  $\longrightarrow$ Ionization + UV Scintillation
- Detection of primary scintillation light (S1) with PMTs.
- Charge drift towards liquid/gas interface.
- Charge extraction liquid/gas at high field (5 kV/cm) between ground mesh (liquid) and anode (gas)
- Charge produces proportional scintillation signal (S2) in the gas phase (10 kV/cm)
- 3D position measurement:
  - X/Y from S2 signal. Resolution few mm.
  - Z from electron drift time (~1 mm).



Background Discrimination in Dual Phase Liquid Xenon TPC's

Ionization/Scintillation Ratio S2/S1

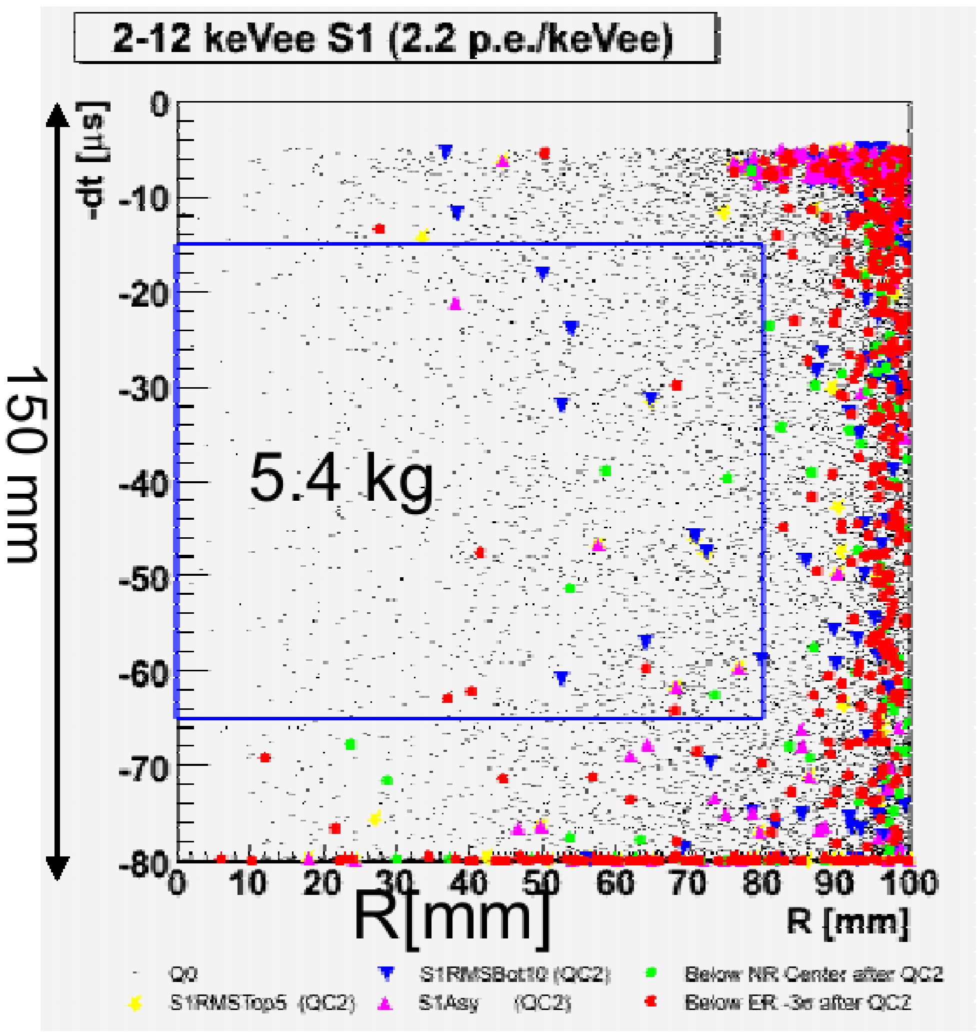


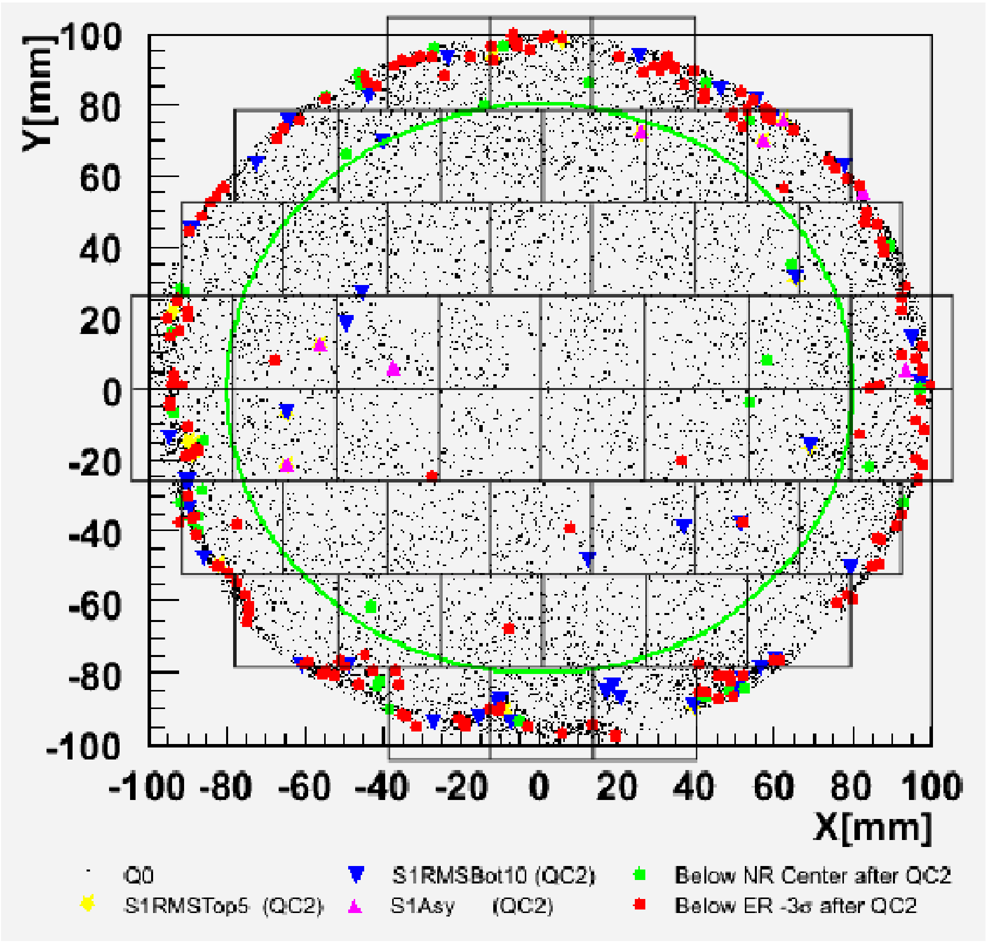


Background Discrimination in Dual Phase Liquid Xenon TPC's

3D Position Resolution: fiducial cut, singles/multiples

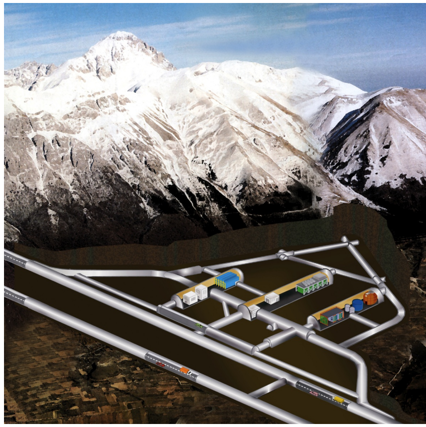
XENON10





The XENON Program

Collaboration: US (3) + China (1) + France (1) + Italy (2) + Japan (1) + Portugal (1) + Switzerland (1) + Germany (2) + ...



GOAL: Explore WIMP Dark Matter with a sensitivity of $\sigma_s \sim 10^{-47}$ cm^2.

- Requires ton-scale fiducial volume with extremely low background.

CONCEPT:

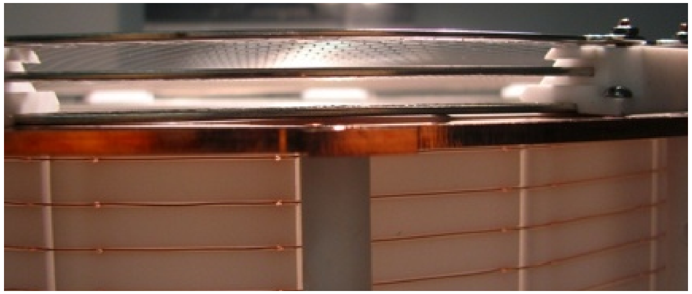
- Target LXe: excellent for DM WIMPs scattering.
  - Sensitive to both axial and scalar coupling.
- Detector: two-phase XeTPC: 3D position sensitive, self-shielding.
- Background discrimination: simultaneous charge & light detection (>99.5%).
- PMT readout with >3 pe/keV. Low energy threshold for nuclear recoils (~5 keV).

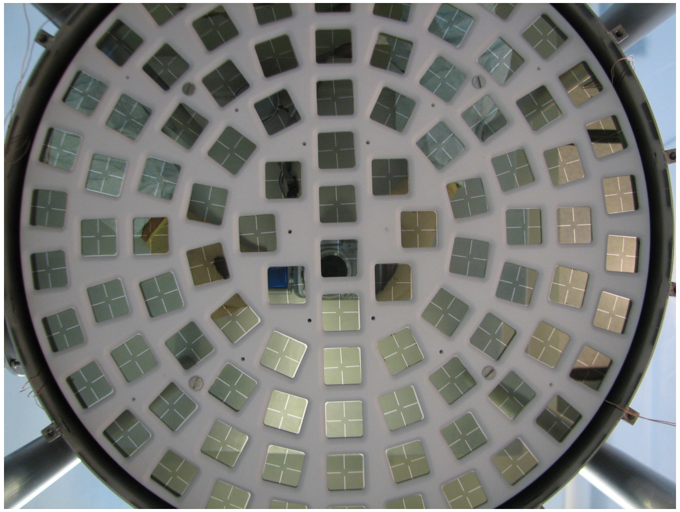
PHASES:

R&D	XENON10	XENON100	XENON1T
Start: 2002	2005-2007	2008-2011	2011-2015
	Proof of concept. Total mass: 14 kg 15 cm drift. Best limit in '07: $\sigma_s \sim 10^{-43}$ cm^2	Dark Matter run ongoing. Total mass: 170 kg 30 cm drift. 11 days: $\sigma_s \sim 3 \times 10^{-44}$ cm^2 Goal: $\sigma_s \sim 2 \times 10^{-45}$ cm^2	Technical design studies. Total mass: ~2.4 t 90 cm drift. Goal: $\sigma_s \sim 3 \times 10^{-47}$ cm^2

The Current Generation: XENON100 (2008-2011)

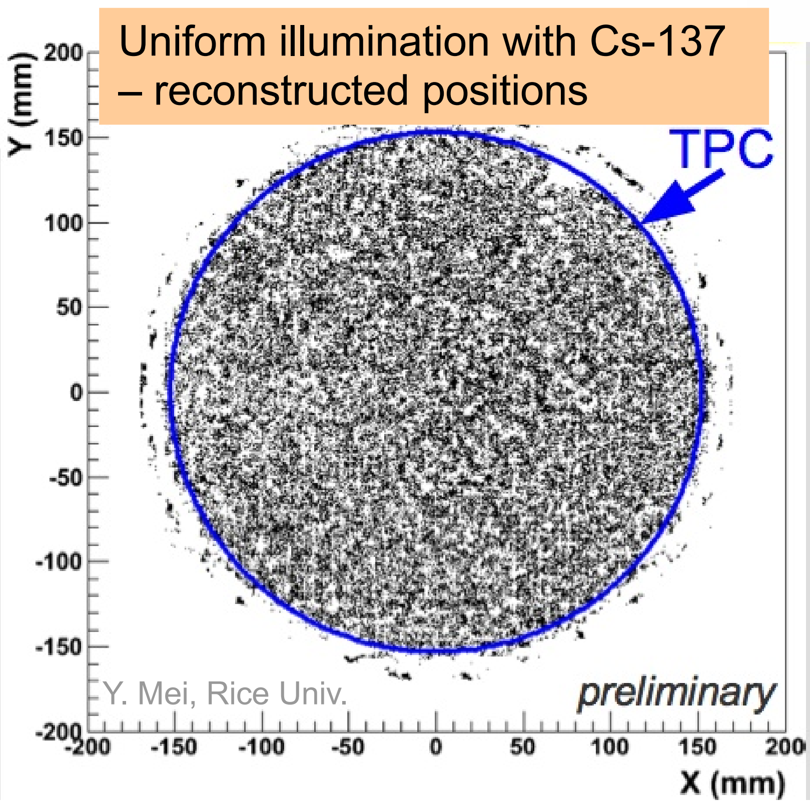
- 100 times lower background than XENON10
  - Material screening
  - Active LXe Veto
  - Addition of inner Cu layer to XENON10 shield
  - Cryocooler/Feedthroughs outside shield
  - Low activity stainless steel
  - LXe self-shielding
- ~7 times larger target mass
  - 62 kg in target volume, 165 kg total LXe
- New PMTs with lower activity and high QE
- Improved electronics, grids, ...
- Gamma & neutron calibrations.
- DM search started 1/13/2010.

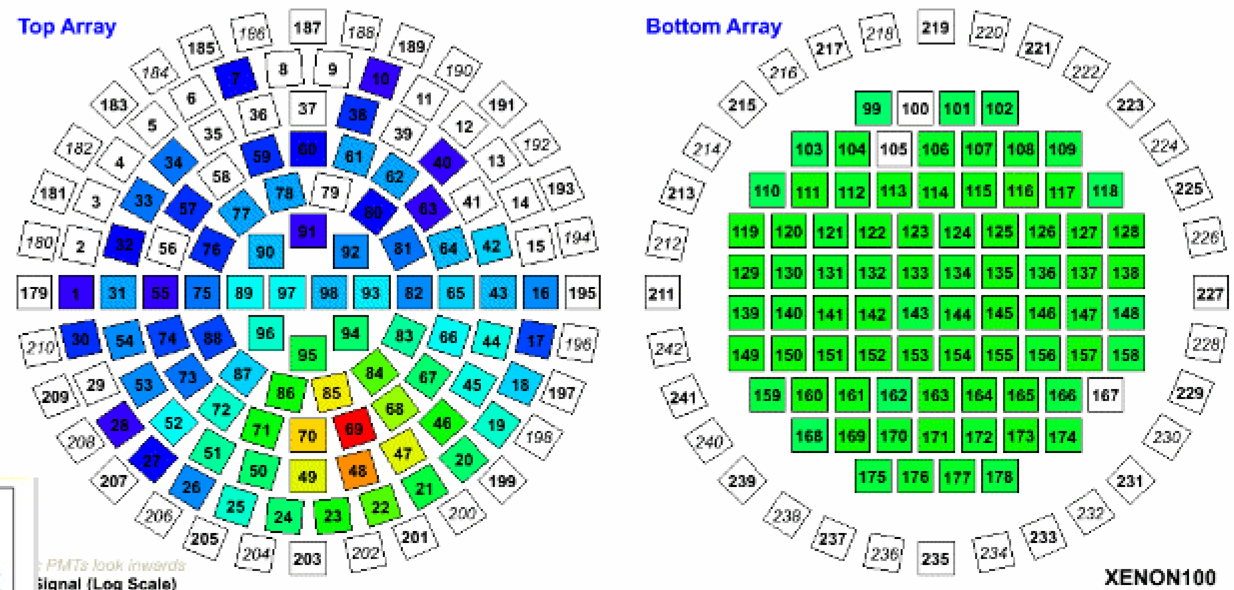


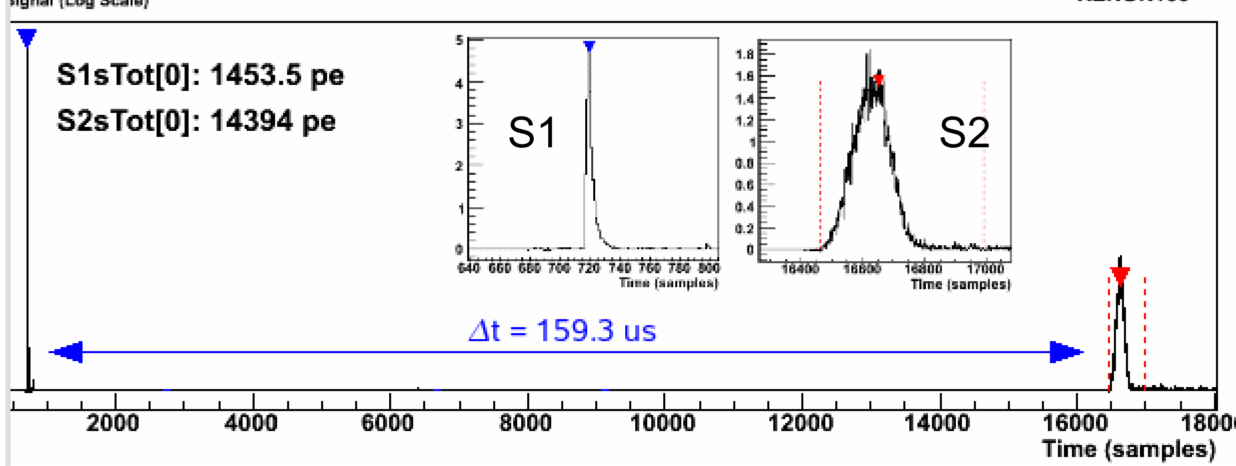


Event Signatures in XENON100

- Position Reconstruction with S2 signal on top PMT array.

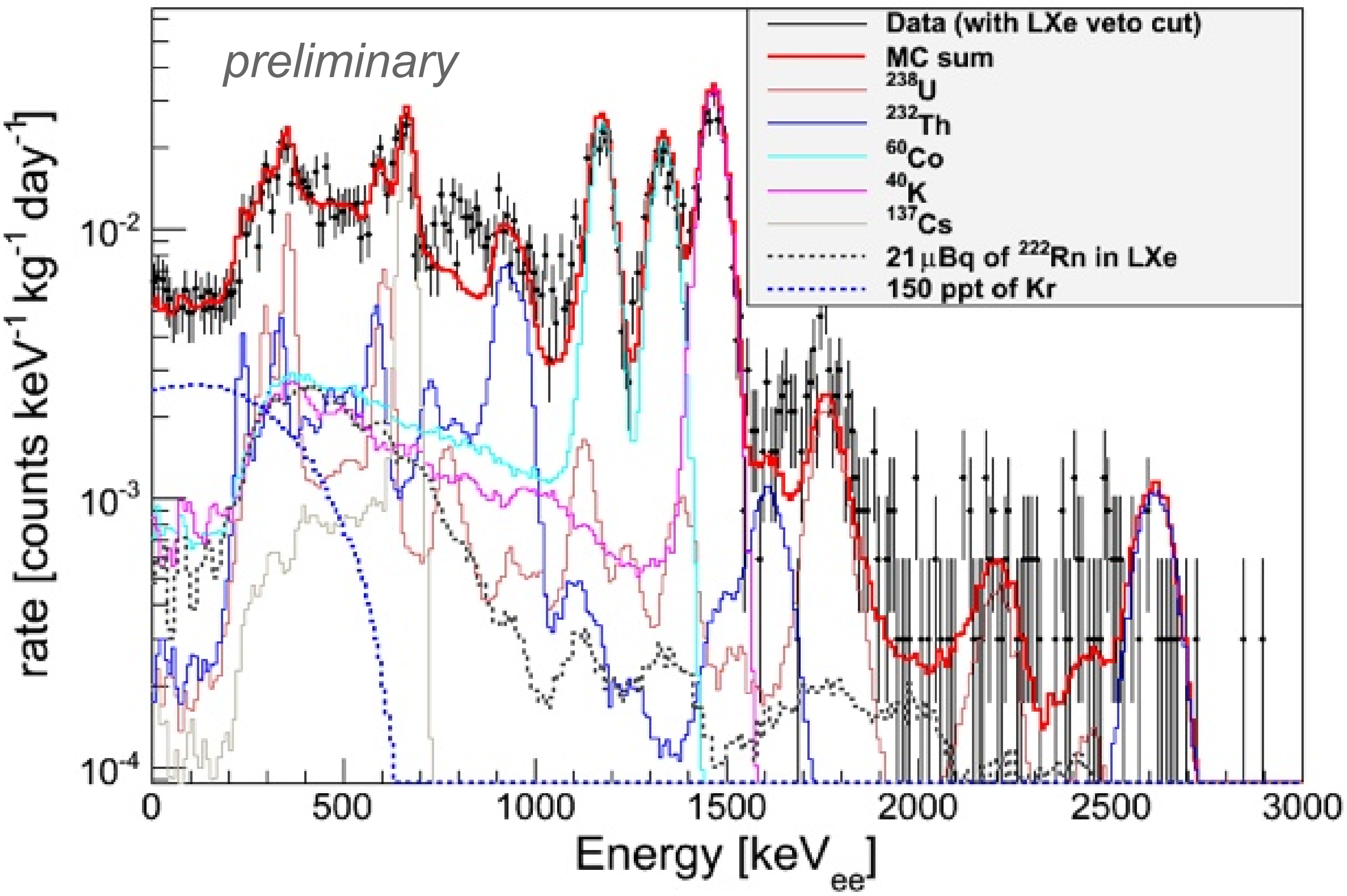




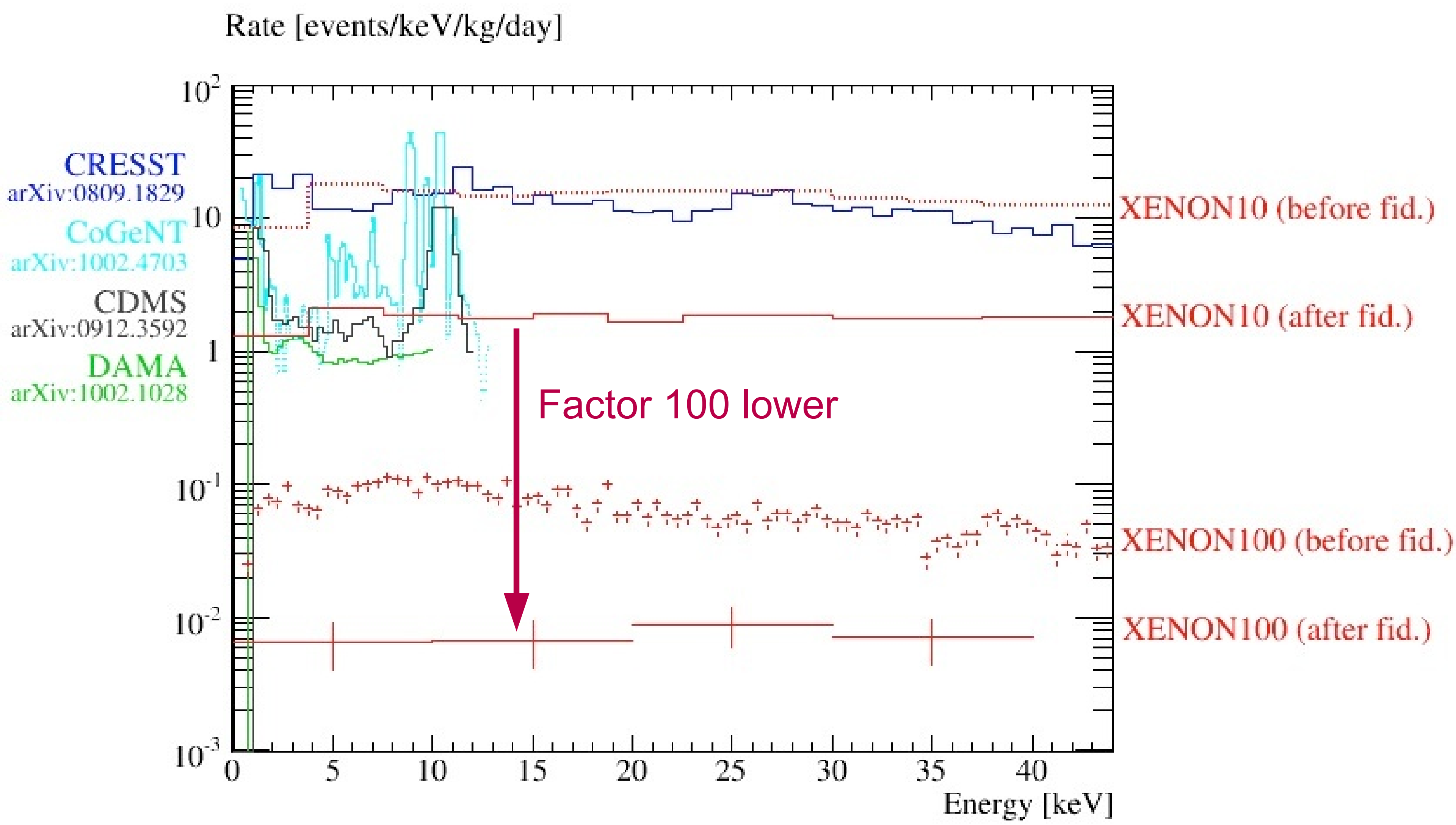


Drift length = 1.84 mm/μs × 159.3 μs = 293 mm

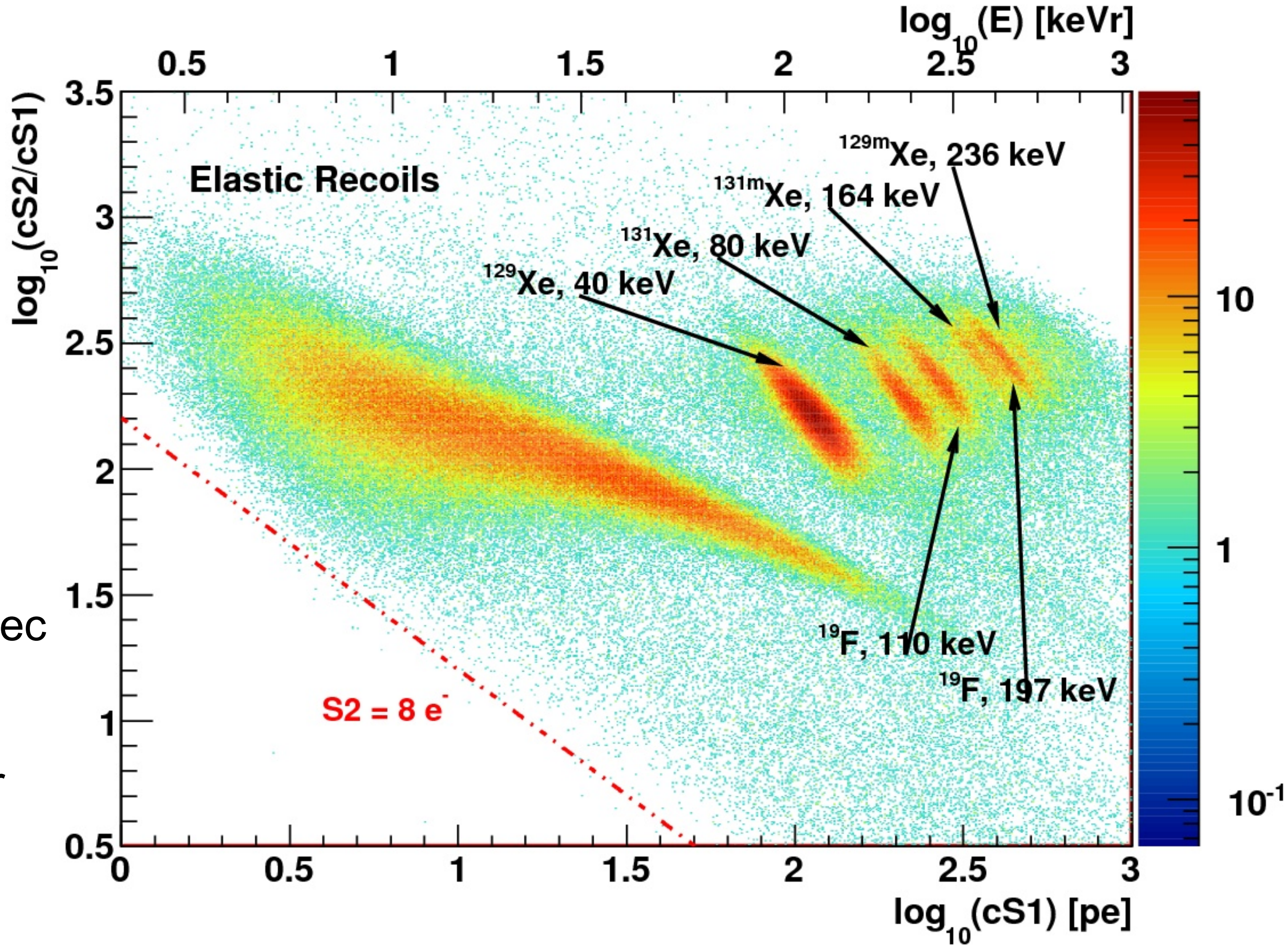
XENON100: Understanding the Background



The Lowest Background Dark Matter Detector



Neutron Calibration of XENON100



- 3.7 MBq (220 n/s) AmBe source from Dec 15-18 '09
- 3×10^6 events in 3 d
- 5×10^4 single scatter nuclear recoils <100 keVr.

- High statistics to be able to describe the nuclear recoil band up to higher energies.
- Neutron calibration also gives gammas from inelastic recoils and activation: used to infer the spatial dependence of S1 and S2 signals.

Nuclear Recoil Energy Scale

$$E_n \times L_{eff}(E_n) = \frac{S1}{L_e} \times \frac{S_e(\vec{\epsilon})}{S_n(\vec{\epsilon})}$$

$$L_{eff}(E) = \frac{L_n(E)}{L_e(E_0)}$$

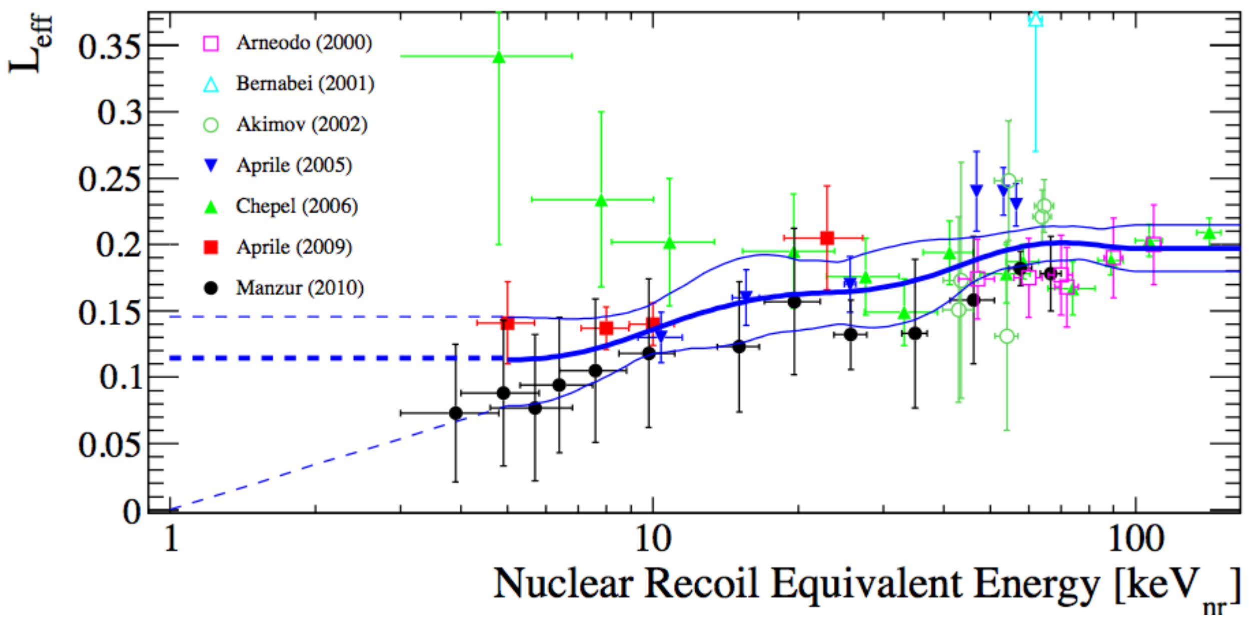
L_{eff}: Relative scintillation efficiency of nuclear recoils at zero field

L_e: Light yield [p.e./keV] for electron recoils at reference energy E_0 (122 keV)

$S1$: primary scintillation signal

S_e: Light quenching due to field for electron recoils at energy E_0

S_n: Light quenching due to field for nuclear recoils

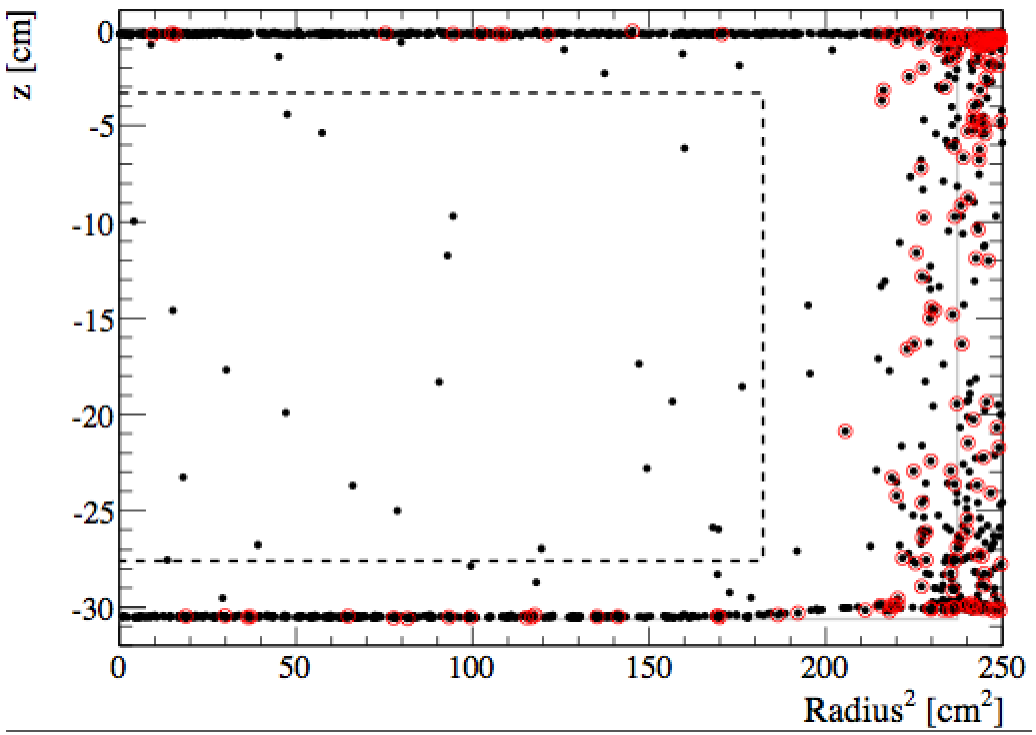


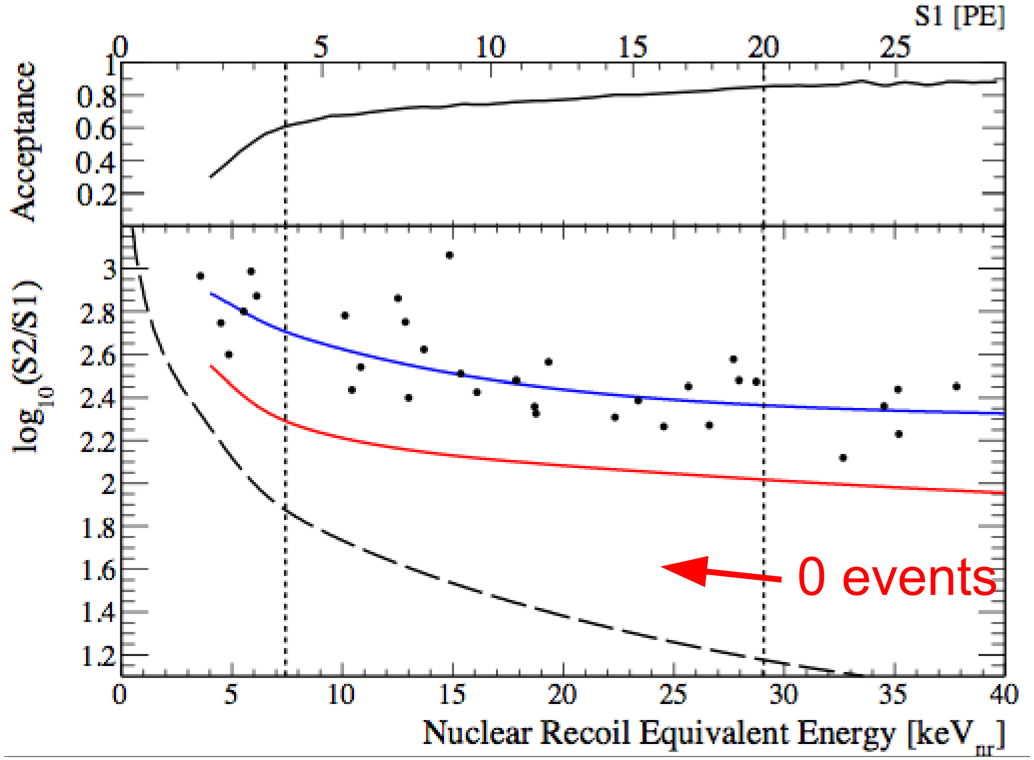
- Fit of available data to relative scintillation efficiency for nuclear recoils.
- Ongoing efforts to measure L_{eff} with higher accuracy.
- XENON100: [4-20] pe ~ [8.7-32.6] keVr

Data:
Arneodo 2000
Bernabei 2001
Akimov 2002
Aprile 2005
Aprile 2009
Sorensen 2009
Manzur 2010

Analysis of “First Light” XENON100 Data

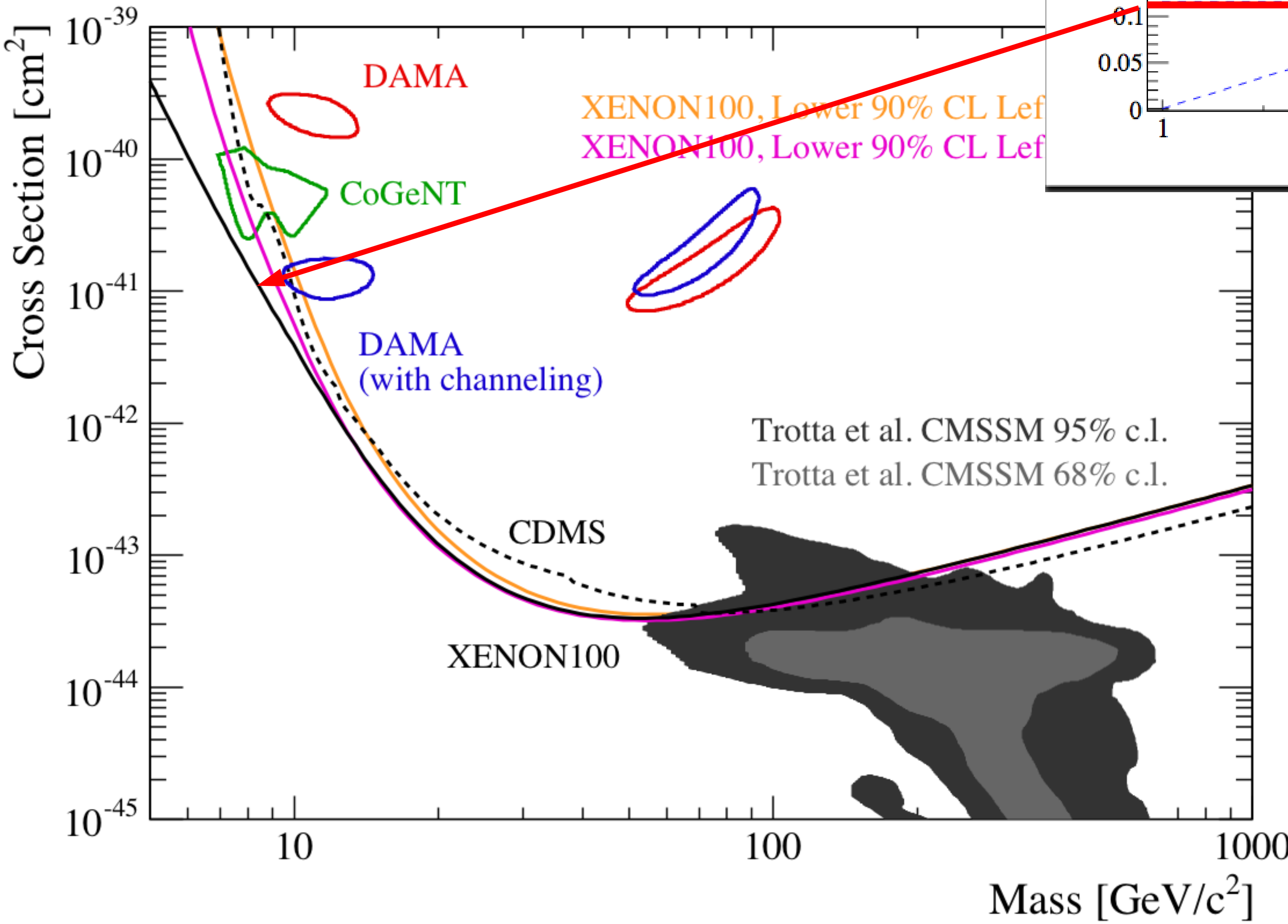
- 11.2 live days of background data from October-November 2009
- Non-blind analysis: but cuts optimized only on neutron and gamma calibration data.
- Only basic event selections are applied.
- 170 kg days exposure **background-free**.

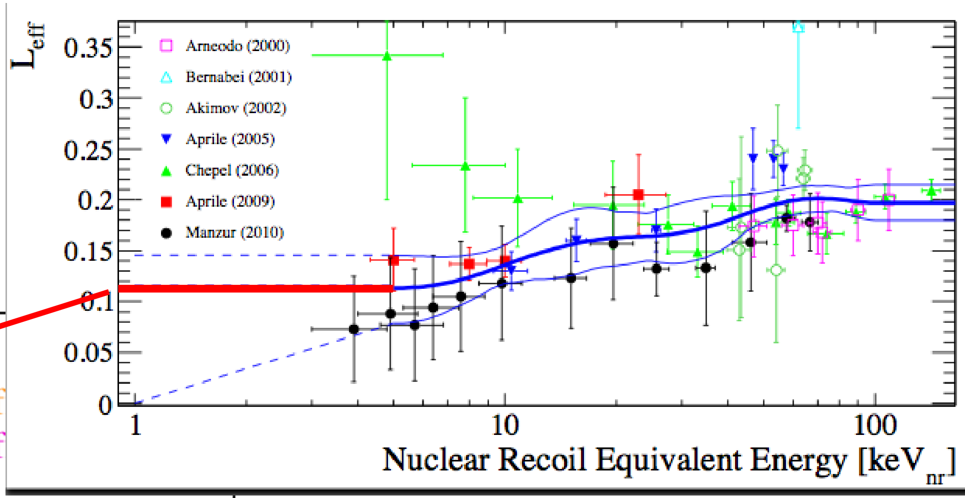




XENON100 Spin-Independent Limit

- 11.2 live days.
- 170 kg d spectrum-averaged exposure.
- Best SI upper limit of
  3.4×10^{-44} cm^2 @ M_{DM} = 55 GeV/c^2

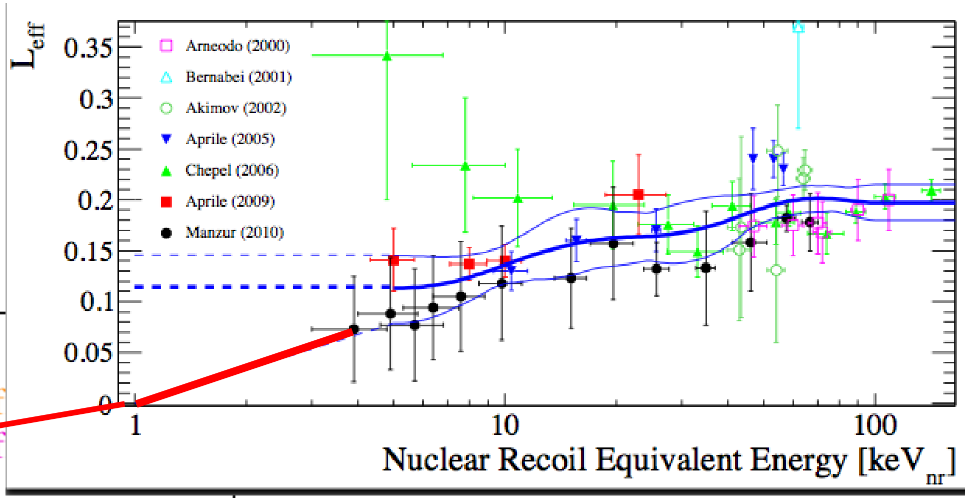


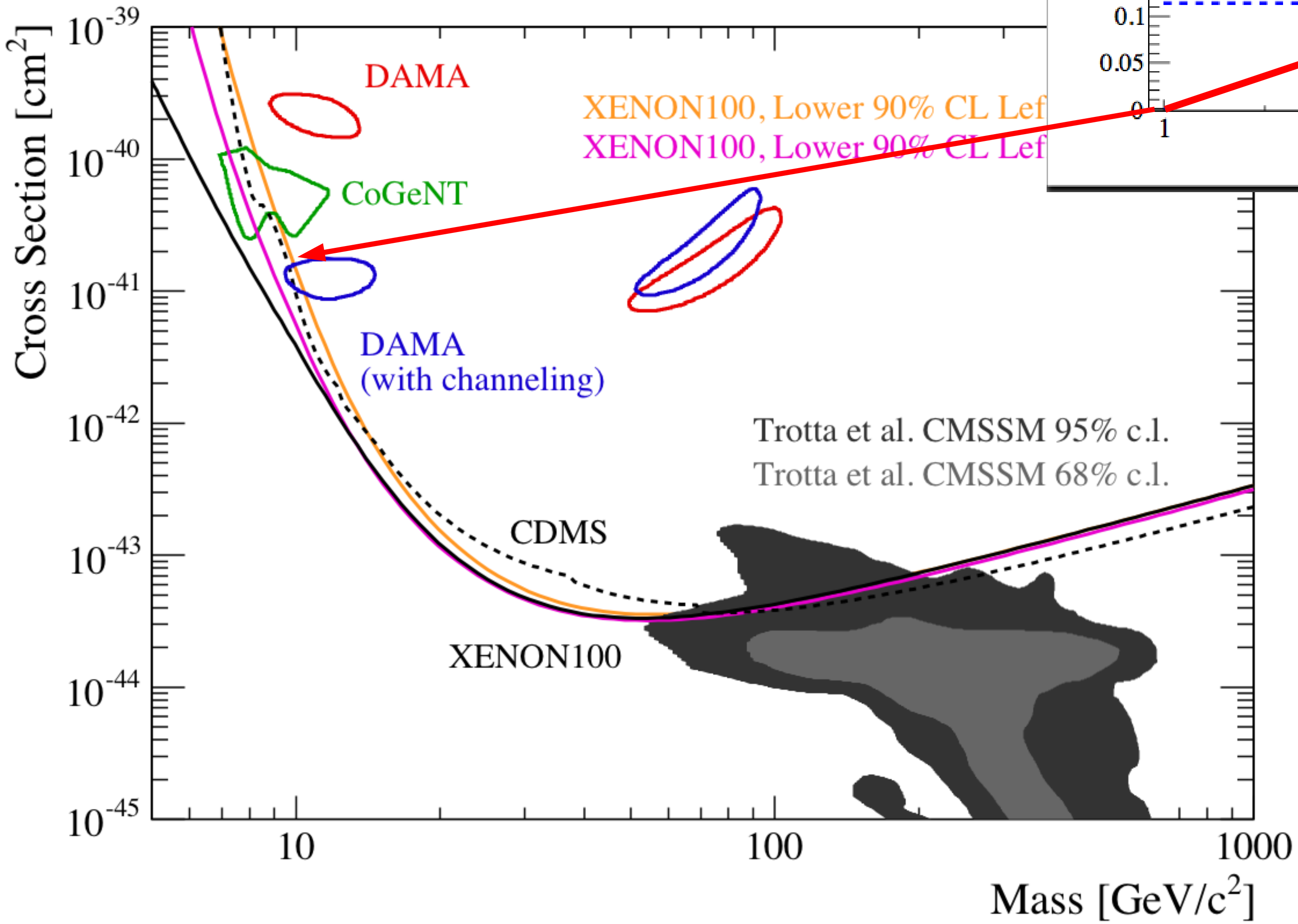


L_{eff} : global fit with constant extrapolation.

XENON100 Spin-Independent Limit

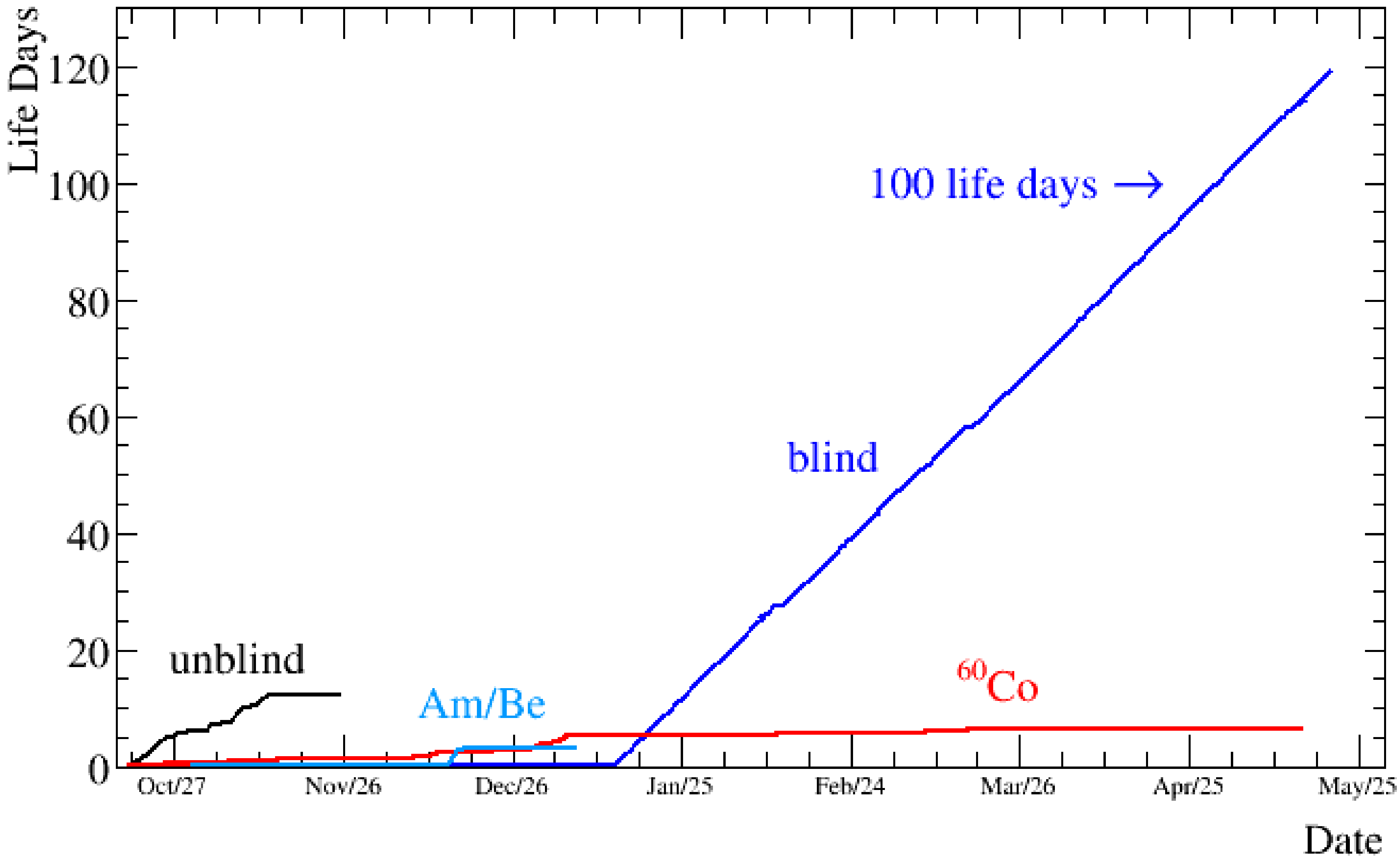
- 11.2 live days.
- 170 kg d spectrum-averaged exposure.
- Best SI upper limit of
  3.4×10^{-44} cm^2 @ M_{DM} = 55 GeV/c^2





L_{eff} : lower 90%CL contour of global fit with logarithmic extrapolation.

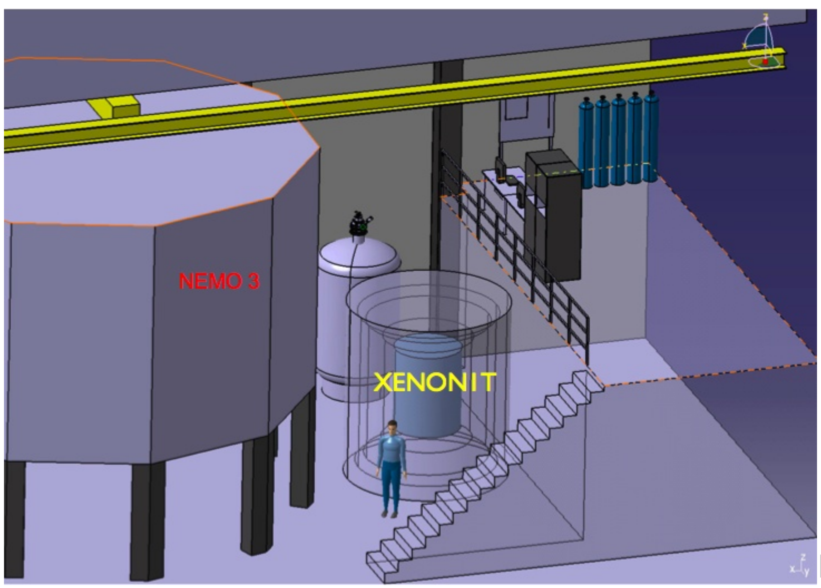
Prospects: XENON100 Blinded Data

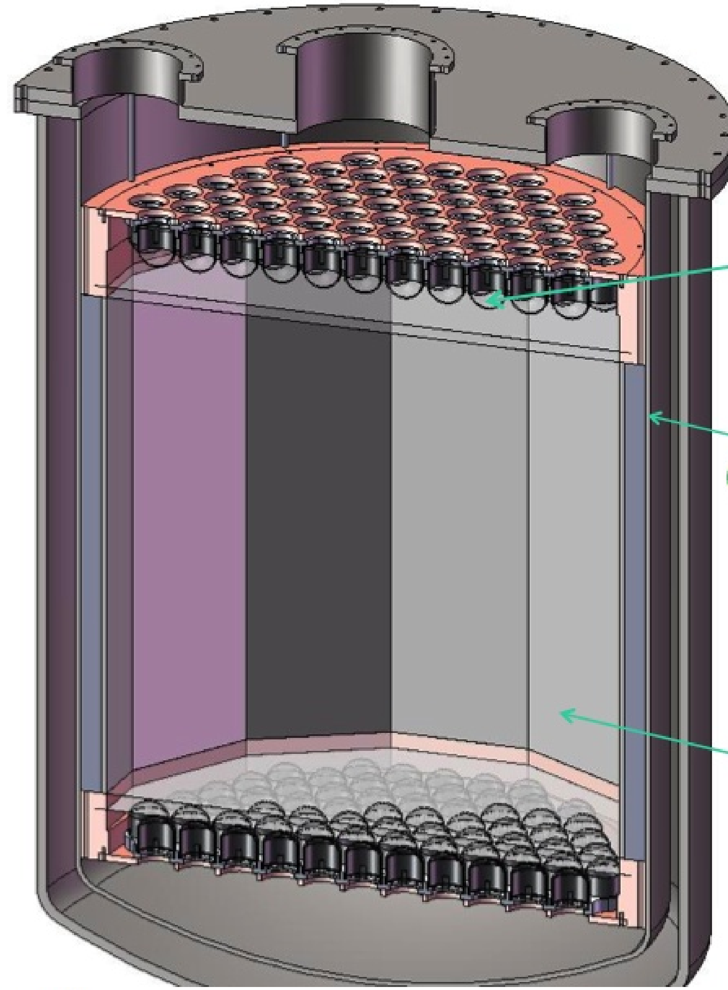


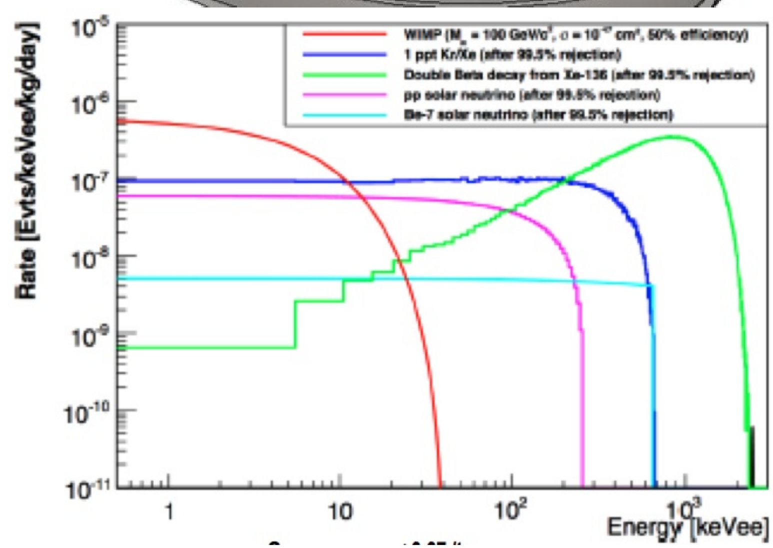
- We have already accumulated 11 times more data (~120 live days blinded) than used in this result.

The Future: XENON-1T
(2011-2015)

- 1t fiducial mass LXe detector to explore $\sigma \sim 3\text{x}10^{47}$ cm^2
- Pre-DUSEL "G2" experiment (PASAG)
- Technical proposal in preparation
- Location: LNGS or LSM
- 2 x 121 3" QUPID's
- Capital cost: ~ $8M, 50% by US
- Collaboration:
  XENON100 + Bologna + Nikhef + WIS







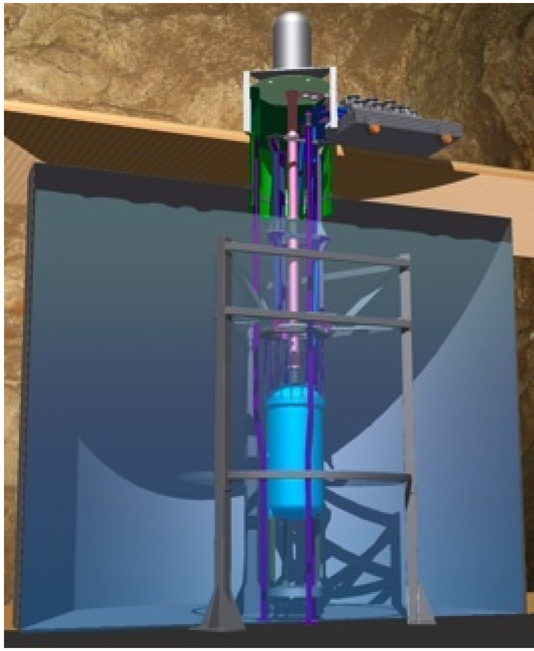
Other Noble Liquid DM Detectors

Single Phase

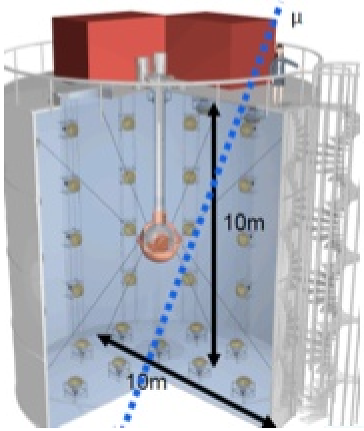
XMASS, Japan
800 kg(100 kg fiducial)
start in 2010?

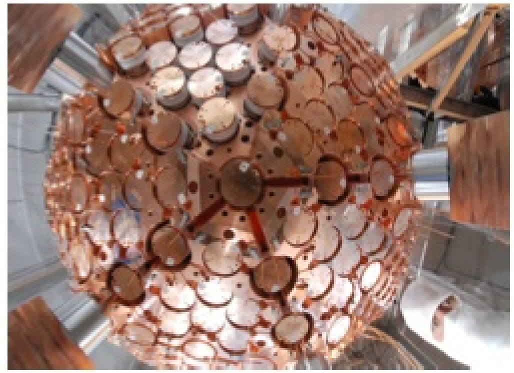
Double Phase

LUX @ Homestake
350 kg (100 kg)

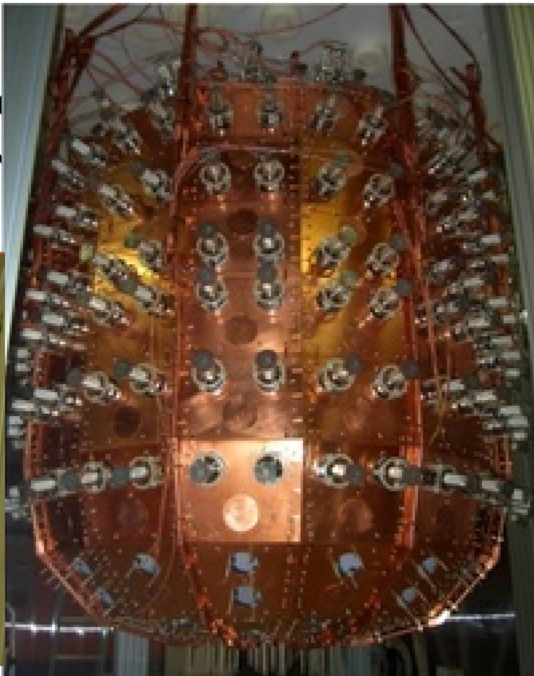


LXe



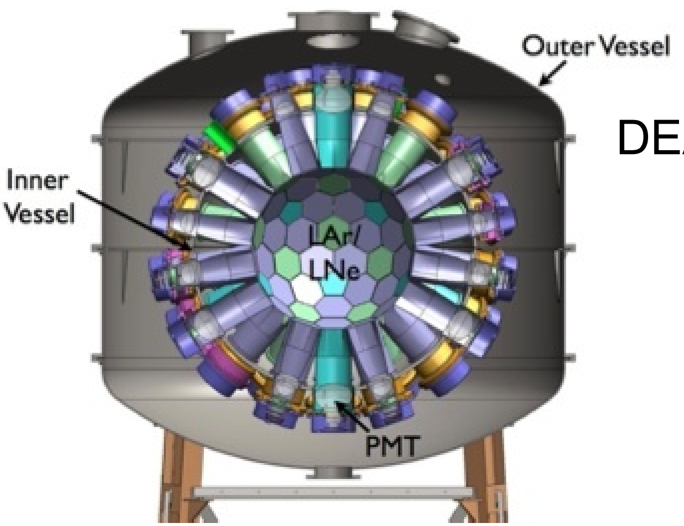


WARP @ LNGS
140 kg LAr in 8t LAr shiel
ArDM: 1 ton LAr @ CERN



LAr

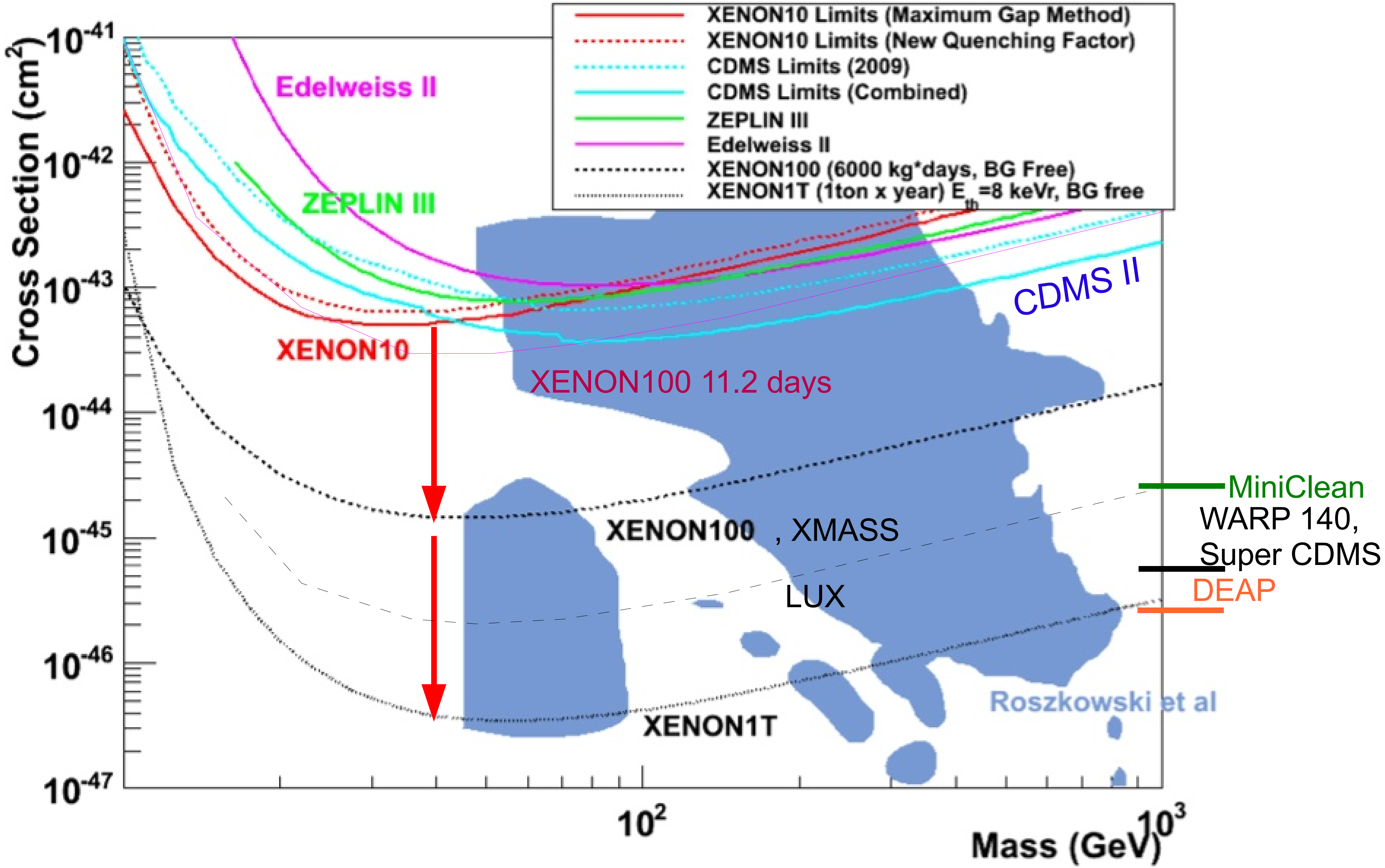
DEAP & MiniClean @ SnoLab



DEAP: 3.6 ton LAr

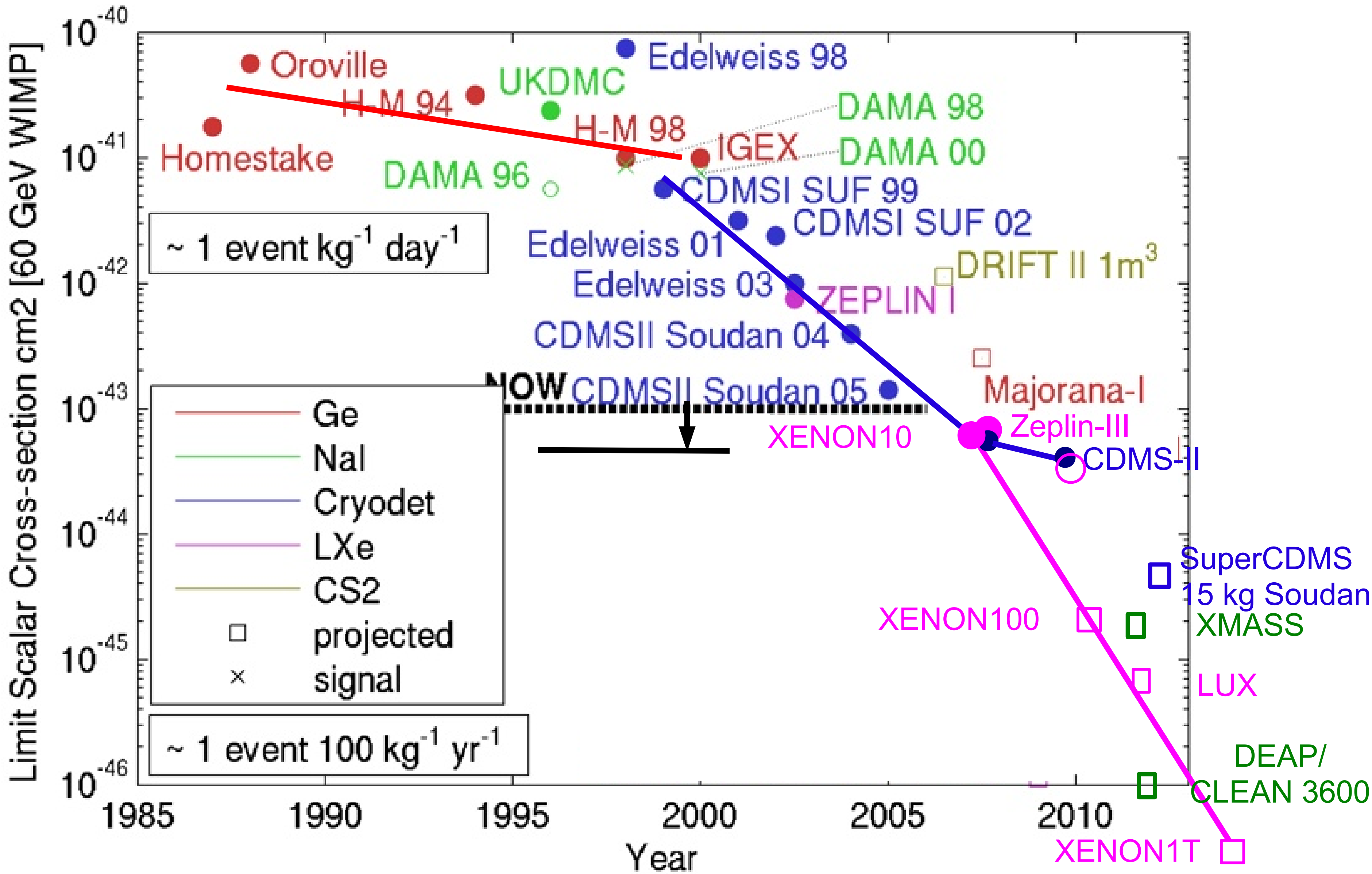
The Future of WIMP Searches

Spin-Independent Sensitivity (indicative)



DM Direct Searches - Progress Over Time

Spin-Independent Interactions



Plot updated from DM Review: R. Gaitskell, Ann. Rev. Nucl. and Part. Sci. 54 (2004) 315-359

Summary & Outlook

- Dark Matter direct searches have advanced in sensitivity by >2 orders of magnitude in the last decade.
- Several exciting new results in the last year: Dark Matter signals everywhere? Low mass WIMPs? Or are we getting carried away? More data on the way!
- Noble liquid detectors have matured, and will likely set the pace in the coming 5+ years, challenging the previous predominance of the cryogenic Germanium technology.
- New approaches in cryogenic Ge aim at making this technology more scalable. Big step in background reduction with interleaved charge readout.
- Bubble chamber technology: big progress in background control, and interesting prospects if the alpha background can be further reduced.
- XENON100:
  - A first analysis of 11.2 live days proves its exceptionally low background level, and puts its sensitivity on par with CDMS-II.
  - Operating in DM search mode since January.
    Will provide order of magnitude improvement in sensitivity later this year.
  - Challenge to low mass WIMP interpretation, but so far large systematic uncertainties below ~10 GeV/c^2 due to uncertainty in energy scale.
- *Stay tuned for more results from direct Dark Matter searches!*

Thank you.

BACKUP SLIDES

The XENON100 Collaboration

COLUMBIA
E. Aprile

RICE
U. Oberlack

UCLA
K. Arisaka, H. Wang

ZURICH
L. Baudis

COIMBRA
J. M. Lopes

LNGS
F. Arneodo

Countries:

USA (3)
Switzerland (1)
Portugal (1)
Italy (1)
Germany (2)
China (1)
France (1)

~ 50 collaborators

MÜNSTER
C. Weinheimer

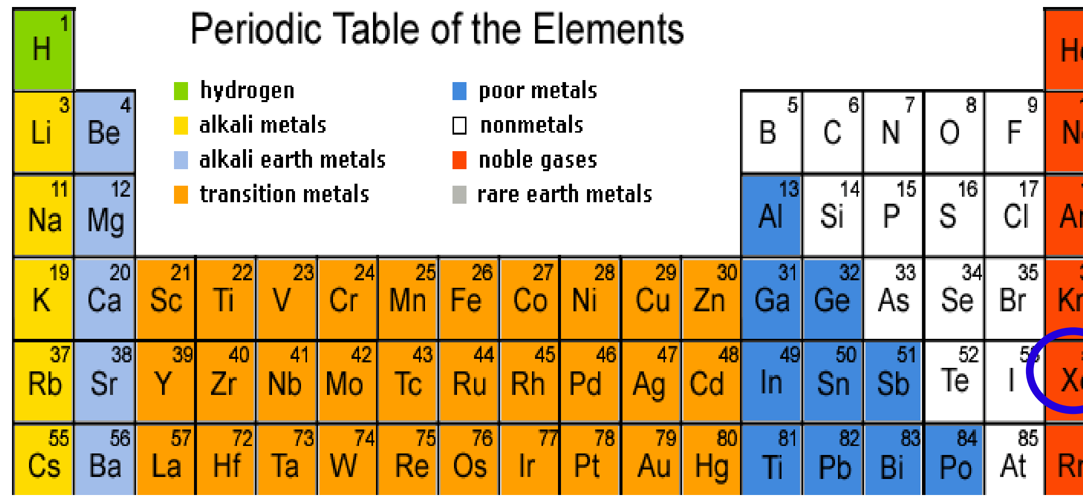
SJTU Shanghai
K. Ni, X. Ji

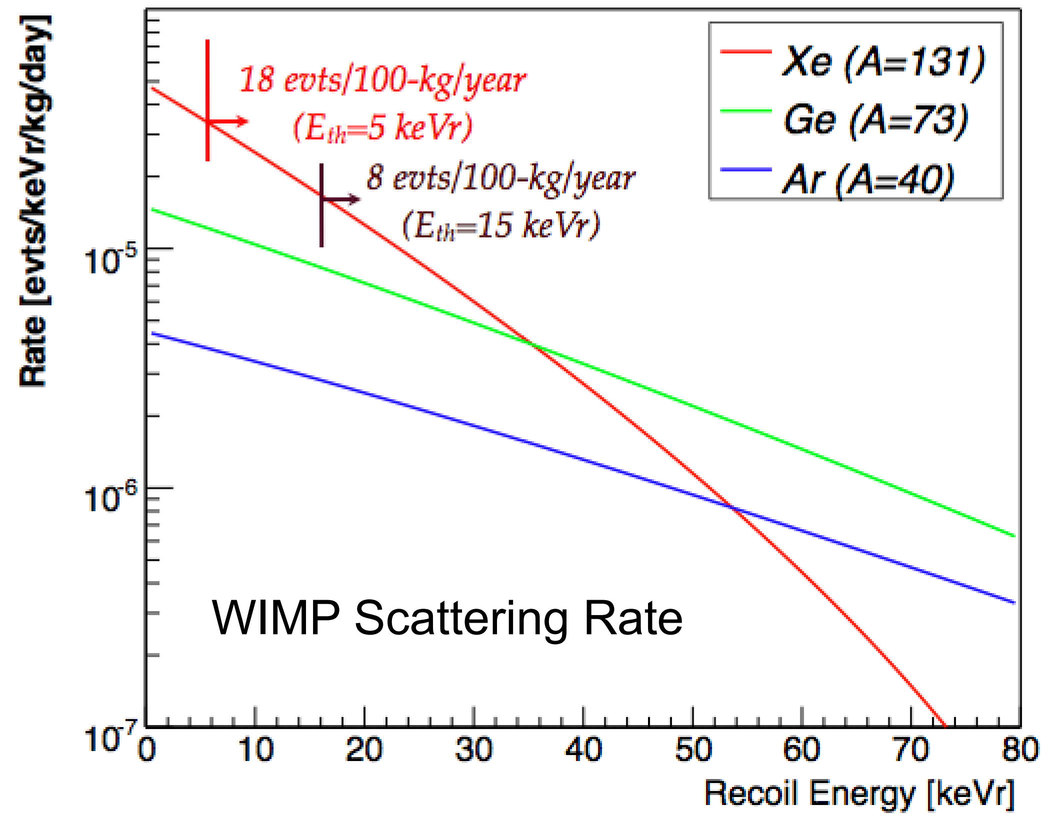
SUBATECH
D. Thers

MPIK Heidelberg
M. Lindner

Liquid Xenon for Dark Matter Search

- Large atomic number A~131 best for SI interactions ($\sigma \sim A^2$).
  Need low threshold.
- ~50% odd isotopes: SD interactions
  If DM detected: probe physics with the same detector using isotopically enriched media.
- No long-lived isotopes.
  Proven Kr-85 reduction to ppt level.
- High Z (54) and density:
  compact & self-shielding
- Scalability to large mass for $\sigma \sim 10^{-47}$ cm^2 ~ 1 evt/ton/yr.
- “Easy” cryogenics (-100°C).
- Efficient and fast scintillator.
- Background discrimination in TPC.
  - Ionization/Scintillation
  - 3D imaging of TPC

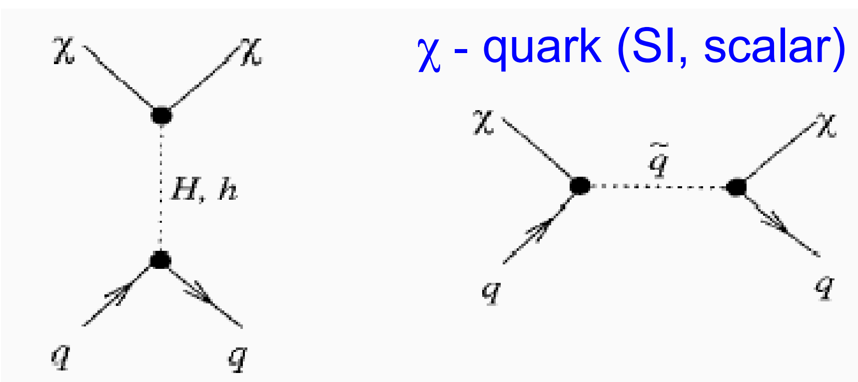


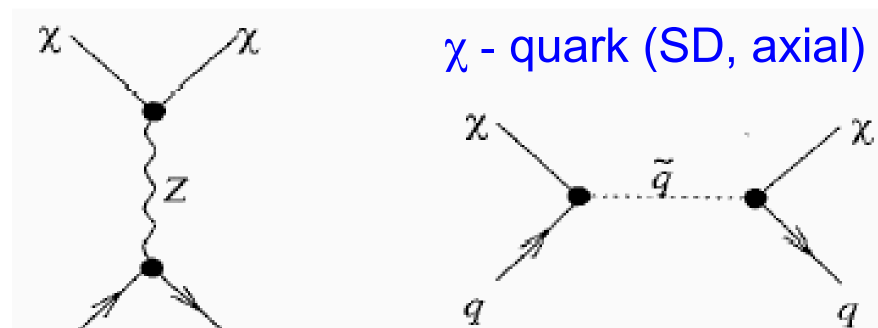


WIMP Scattering Cross Sections

Example: SUSY (but direct searches are sensitive to other models as well)

- Compute cross sections χ – quark and χ – gluon with various SUSY models. Large parameter space, constrained by accelerator and direct search experiments, and cosmology.
  - **spin-independent**: coupling to mass of nucleus. Coherence $\Longrightarrow \sigma \propto A^2$
  - **spin-dependent**: coupling of spins of nucleus and neutralino interaction with paired nucleons in the same energy state cancel => no A^2 enhancement

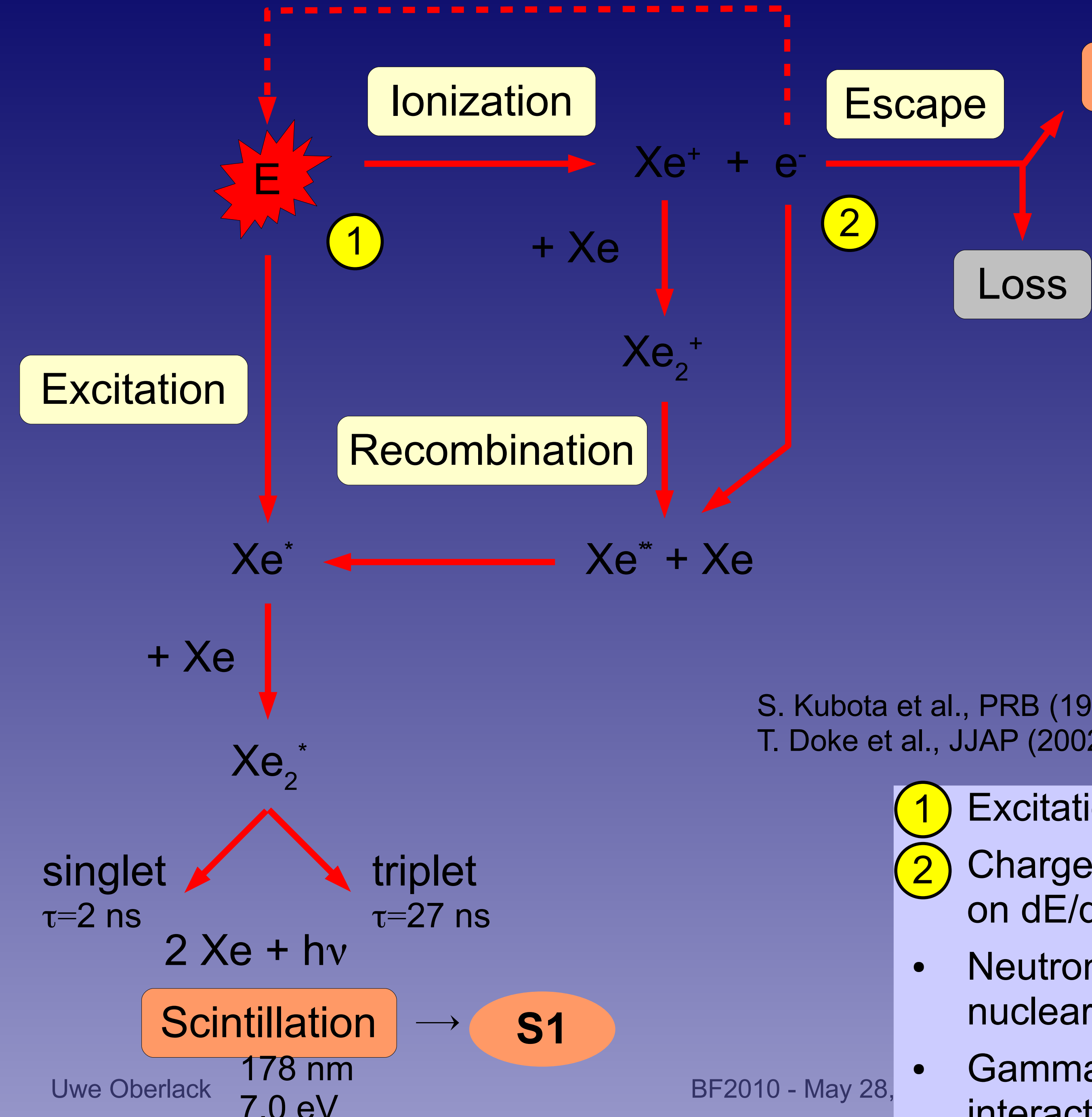




Jungmann et al. '96 Phys.Rep.

- Distribution of nucleons within nucleus: nuclear form factor.
  - SI: Large nuclei gain $\sim A^2$ at small momentum transfer, but lose at higher momentum transfer due to coherence loss.

Ionization and Scintillation in LXe



S. Kubota et al., PRB (1979)
T. Doke et al., JJAP (2002)

Excitation Scintillation:

$$Xe^* + Xe \rightarrow Xe_2^*$$
$$Xe_2^* \rightarrow 2\,Xe + h\nu$$

Recombination Scintillation:

$$Xe^+ + Xe \rightarrow Xe_2^+$$
$$Xe_2^+ + e^- \rightarrow Xe^{**} + Xe$$
$$Xe^{**} \rightarrow Xe^* + \text{heat}$$
$$Xe^* + Xe \rightarrow Xe_2^*$$
$$Xe_2^* \rightarrow 2\,Xe + h\nu$$

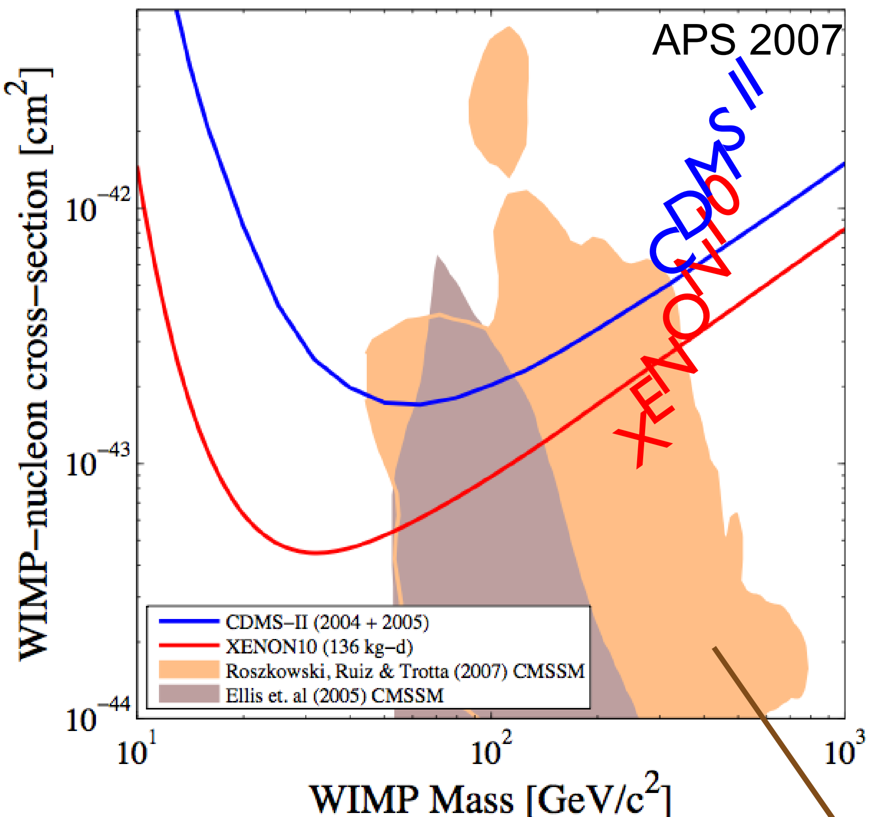
1. Excitation / Ionization depends on dE/dx.
2. Charge signal / Recombination depends on dE/dx and electric field.

- Neutrons, WIMPs:
  nuclear recoil O(10 keV), dE/dx high.
- Gamma-rays, betas:
  interactions with electrons, dE/dx low.

The Previous Generation: XENON10
(2005-2007)
World Leading Upper Limits

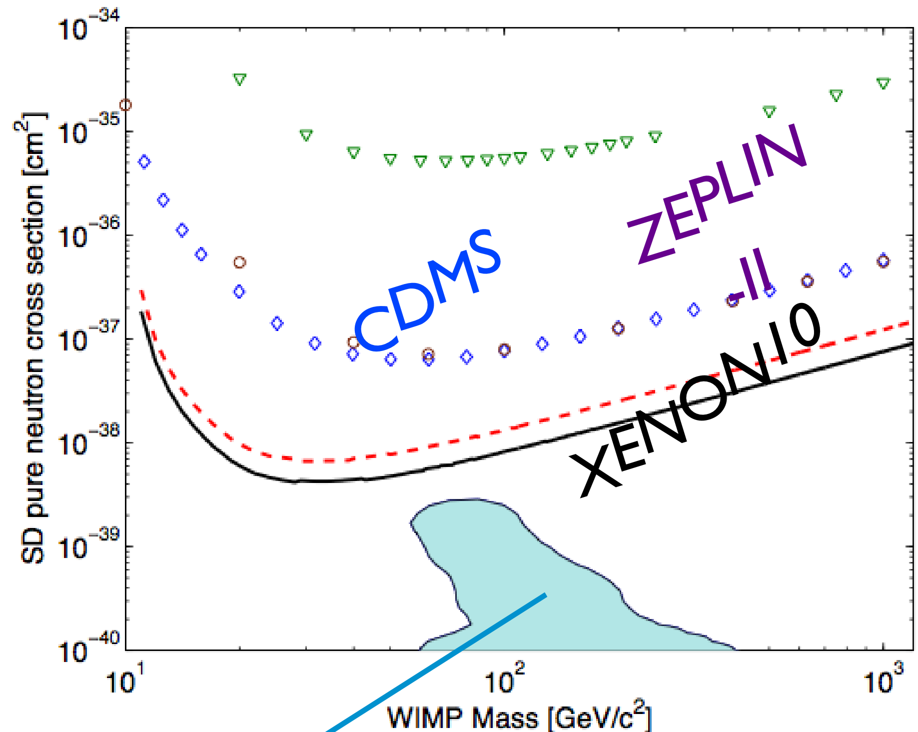
Spin-independent

Phys. Rev. Lett. ***100****, 021303 (2008)*



Spin-dependent

Phys. Rev. Lett. ***101****, 091301 (2008)*

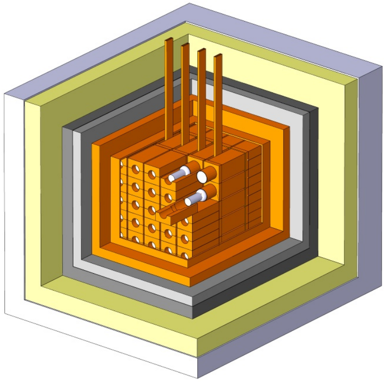


8.8 x 10^{-44} cm^2 at 100 GeV
4.5 x 10^{-44} cm^2 at 30 GeV
(no background subtraction)

Constrained Minimal Supersymmetric Model

6 x 10^{-39} cm^2 at 30 GeV
(no background subtraction)

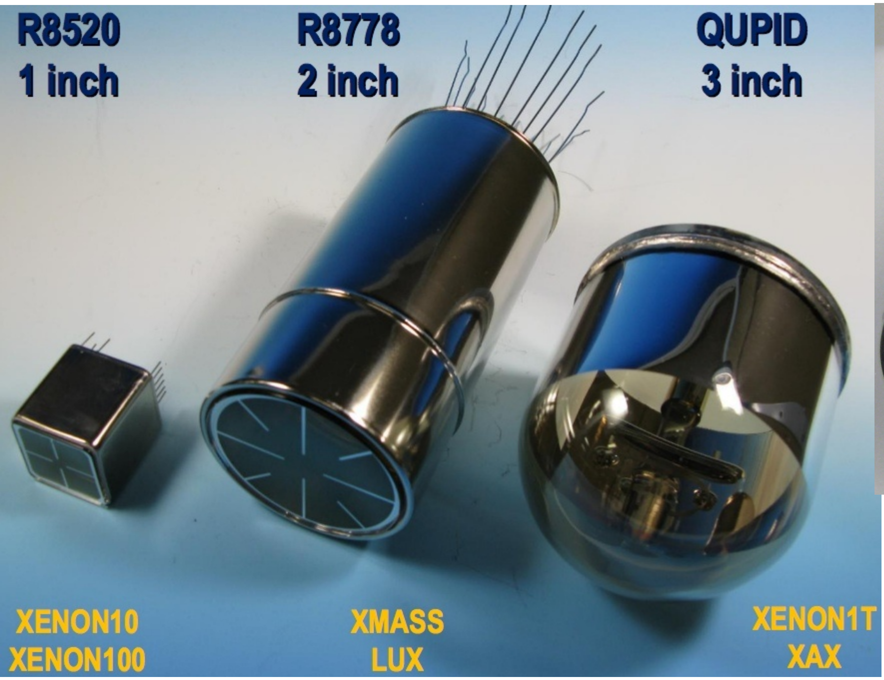
Testing DAMA/LIBRA
Annual Modulation with XENON100



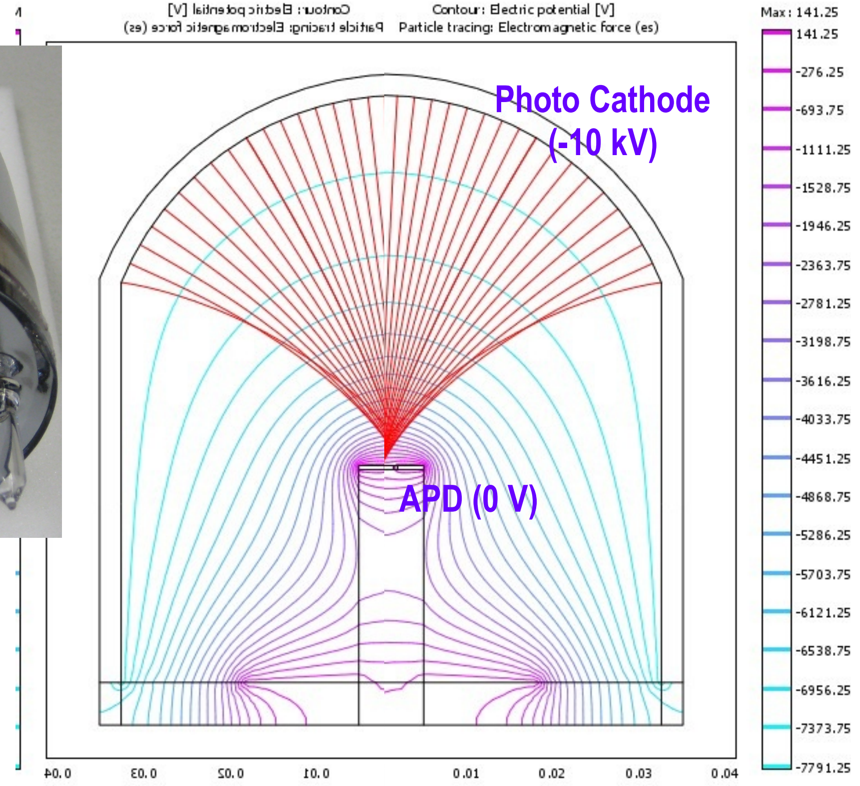
- Xe is an excellent scintillator, similar to NaI. Energy thresholds are similar.
- Xe and I are next neighbours in the periodic table.
- Liquid Xe is homogeneous, and extremely radiopure.
- XENON100 records all triggered events, with data selections only in software.
  - Study both nuclear recoils **and** interactions with electrons, and **know** what you are looking at!
- Unlike DAMA/LIBRA, XENON100 has background reduction even **without** nuclear recoil suppression, based on 3D position reconstruction and self-shielding.
- Chose a fiducial volume to look for rare events with a background rate two orders of magnitude lower than DAMA/LIBRA.
  - Annual modulation signal DAMA/LIBRA 2-4 keV: ~0.02 events / d / kg / keV
  - Background in DAMA/LIBRA: ~ 1 events / d / kg / keV , signal/bgd ~ 0.02
  - Background in XENON100: ~0.01 events / d / kg / keV , signal/bgd ~ 2 expected
- **With 1 year of data, XENON100 will be more sensitive than DAMA/LIBRA to annual modulation!**
  - 6000 kg d exposure
  - if Xe is similar to NaI in response to DM particles

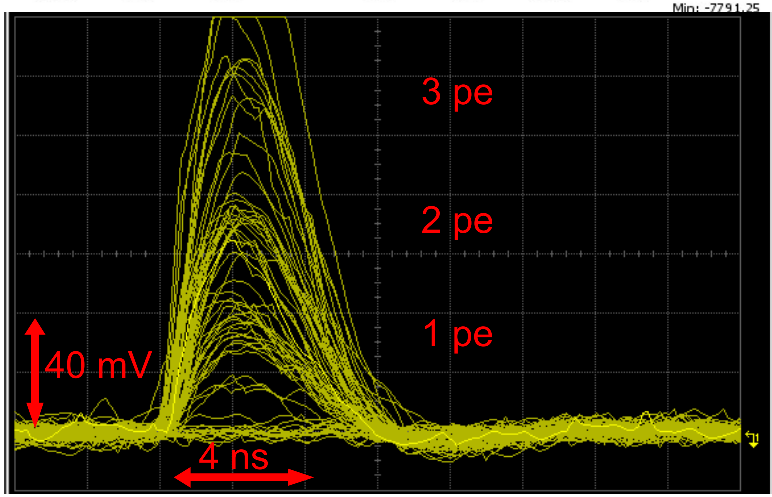
$$\text{sensitivity} \propto \sqrt{\frac{M\,t}{b}}$$

New Photosensor for XENON1T: 3” QUPID



K. Arisaka & H. Wang (UCLA)





- > Ten-fold reduction in radioactivity per unit area. (< 0.02 mBq/cm^2)
- Single photo-electron resolution.
- Single HV supply for many channels.
- Large dynamic range.

The Future of WIMP Searches with XENON

Spin-Dependent Sensitivity